

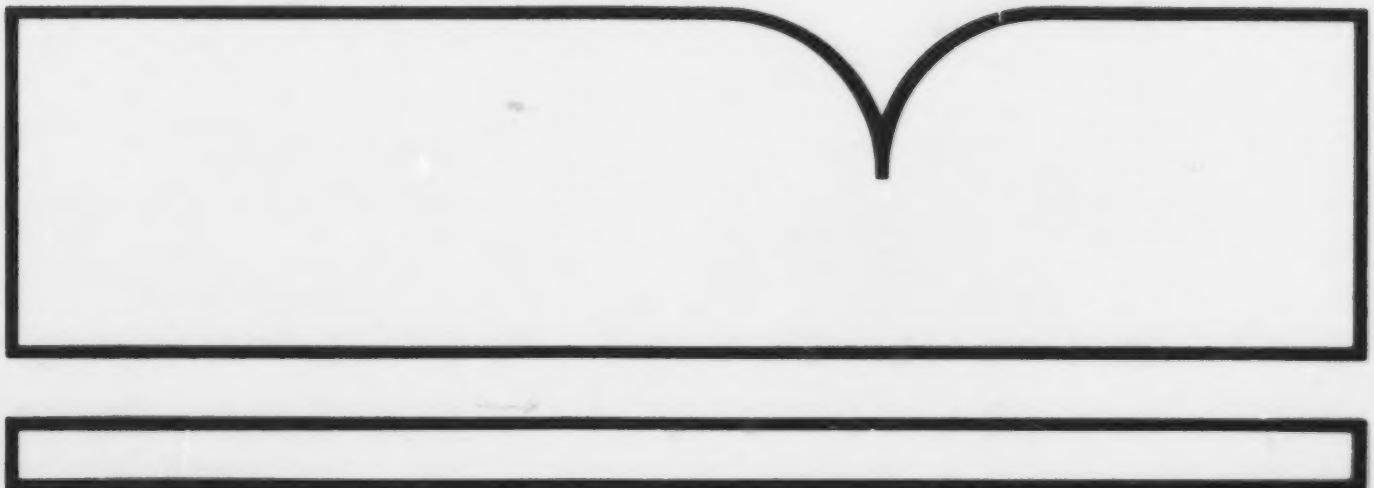
Development of a Baseline for Use in
Assessing Impacts of the Toxic
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Chemicals Industry

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DEVELOPMENT OF A BASELINE
FOR USE IN ASSESSING
IMPACTS OF THE TOXIC
SUBSTANCES CONTROL ACT (TSCA)
ON THE CHEMICALS INDUSTRY

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16. Abstract (Limit: 200 words) A three equation model of innovation in the chemical industry has been developed. The model includes the following three relationships: (1) a technical knowledge production function with technical knowledge as a function of research and development input, (2) a production function with output as a function of conventional inputs (capital, labor, and materials) and a "stock" of knowledge, and (3) a derived demand equation for innovation inputs. The model was tested using data on 48 publicly owned firms covering a 20 year period 1960-1980. Financial data were taken from the firms' 10-K annual reports, and patent data, used as measures of innovation, were obtained from the U.S. Patent Office. The resulting regression estimates (1) supported the hypothesis that all firms have the same elasticity of patenting with respect to their R & D stock, (2) yielded estimates of elasticity of output relative to R & D stock about twice as large as an earlier study, and (3) supported a model of R & D intensity as a function of expected growth rate. The report suggests additional refinements and testing of the model and methods for utilizing it in assessing the impact of the Toxic Substances Control Act.					
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Section 1 Executive Summary

Introduction

Goals

The goal of this project is to provide a means whereby EPA can estimate the impacts of the Toxic Substances Control Act (TSCA) on the chemicals industry and on the national economy. If this capability is developed, EPA will be better able to track the effects of regulatory actions for the purpose of correcting those that have caused too severe adverse effects relative to their benefits and defending other actions that may be unjustifiably blamed for such effects. These estimates will provide a useful comparison with other studies of estimated TSCA impacts. In addition, EPA will be better able to plan and evaluate future regulatory options before they are promulgated.

Project Objectives

The objective of the research work to date is a methodology to produce a baseline forecast against which the effects of TSCA actions can be measured and a model which provides a framework to estimate the impacts on the baseline variables. The baseline consists of a set of variables that describe conditions in the chemicals industry--such as rate of innovation, sales, profits and other measures of business performance--in the absence of TSCA regulation. The model describes the behavioral relationships which are identified among the baseline variables and allows the effects of TSCA impacts to be traced out.

There is general agreement that TSCA is most likely directly to affect those activities in the chemicals industry that relate to innovation; the activities include research, development, testing, and commercialization of new products and processes. Many other factors, including other regulations, affect business performance and make it difficult to isolate the effects of TSCA. Therefore, development of a useful set of relationships that explain innovation--an innovation model or models--is the first priority before serious effort is made to link innovation activities to business performance. Hence the research described in this report has concentrated on the development of baseline variables which relate in a direct way to innovation activities (e.g., number and value of new chemicals, R+D expenditures), and on development of an analytic method and data base that can be used to estimate the baseline variables.

Project Outputs

The primary outputs sought from the selected approach are historical data relating to innovation variables and a model (or models) that depict relationships among those variables. These elements can be used in a number of different ways. The model can be used to project values of the baseline variables for future years. These projections can be compared either with the observed values of these variables (ex post analysis) or with alternative projections of baseline variables generated by adjusting the coefficients of the model to reflect estimates of TSCA impacts (ex ante analysis). The difficulty of attributing ex post differences between projected and actual values to specific TSCA impacts rather than other forecast errors suggests that ex ante analysis may provide more reliable impact estimates.

Industry Scope

The industries of particular interest to EPA are those which produce and/or use chemicals, including petrochemicals. More specifically, EPA has used the Standard Industrial Classification (SIC) Codes to identify affected firms. All firms classified as belonging to SIC group 28 (Chemical and Allied Products) (except those that manufacture pesticides or drugs) are included in the study. Within SIC Group 29 (Petroleum Refining and Related Industries), only petroleum refining is included in the study.

Review of Literature and Evaluation of Methodological Approaches

Prior to selecting the innovation modeling approach described below, the literature on the analysis of TSCA impacts and the impacts of other similar regulations, specifically the 1962 Kefauver-Harris amendments of drug industry regulations, was surveyed and the alternative methodological approaches evaluated. The literature contains two major approaches to modeling innovation: case studies and aggregate analyses of variables such as R+D expenditure and the production of new chemical entities at the company or 4-digit SIC level.

The case study approach is represented by the rate of return methodology pioneered by Edwin Mansfield and others to measure the private and social returns of individual R+D projects. In theory, the approach is to calculate the return on the project based on all identifiable costs and benefits associated with the project. In practice, this procedure has massive requirements for confidential data, making the sample available to the researchers very dependent on the cooperativeness of firms. Using

this approach to estimate impacts for the industry as a whole also entails a number of problems. Even if data for a large sample of case studies could be obtained, it would be difficult to determine whether the sample was representative of the industry and how an analysis of TSCA impacts for this sample could be extrapolated to the industry as a whole.

Aggregative approaches to the analysis of innovation are more varied. In terms of their effect on innovation, the 1962 Kefauver-Harris amendments to regulations covering the pharmaceuticals industry may be the regulatory "event" which provides the closest precedent for TSCA regulations, although there are important differences as well. Therefore, the literature which attempts to assess the impact of the 1962 amendments is a fruitful source of approaches for this study. It is found that the drug studies highlight some areas of interest to TSCA, but that the majority of the literature is not very useful. Generally, the drug studies are data constrained, post hoc, single equation analyses dealing with very different regulatory requirements. All these factors are not particularly helpful in an evaluation of TSCA's effects on the chemicals industry. Nevertheless, they do provide a helpful starting point by focusing on the relationships between R+D expenditures, measures of innovation such as new chemical entities, demand-side factors such as expected sales growth, and supply-side factors such as the depletion of research opportunities. If nothing else, they highlight the difficulty of associating a particular impact with a particular government regulation, even though the impact itself is quite dramatic.

Another aggregative method was proposed by our subcontractor, Charles River Associates. It was proposed to estimate a single-equation "reduced

form" model which relates a measure of innovation such as patents or new chemical entities to variables which affect either the demand or supply of innovation, including research factor supplies and prices, the degree of market concentration, the profitability and growth prospects of the chemicals industry, and the research intensity of the industry. Although it shares many features with the methodology eventually adopted, it was not adopted because of its lack of differentiation of different phases of the innovation process and consequent difficulties of interpretation.

The Innovation Model

Introduction

This section describes the three-equation model of innovation on which our work is focused. The model includes the following three relationships:

- 1) a technical knowledge production function with technical knowledge as a function of research and development inputs;
- 2) a production function with output as a function of conventional inputs (capital, labor, and materials) and a "stock" of knowledge; and
- 3) a derived demand equation for innovation inputs.

This approach was chosen because it presents a plausible structuring of the relationship between R+D activities, the outputs of those activities in terms of their effect on factor productivity (thereby affecting sales, profits and other indicators of business activity), the feedback of these affects on the demand for R+D, and other factors which determines the costs of R+D. It is based on the work of Griliches, Schankerman, Pakes, and others. The model can be estimated at the firm level using publicly available data, although the analysis would be enhanced if confidential

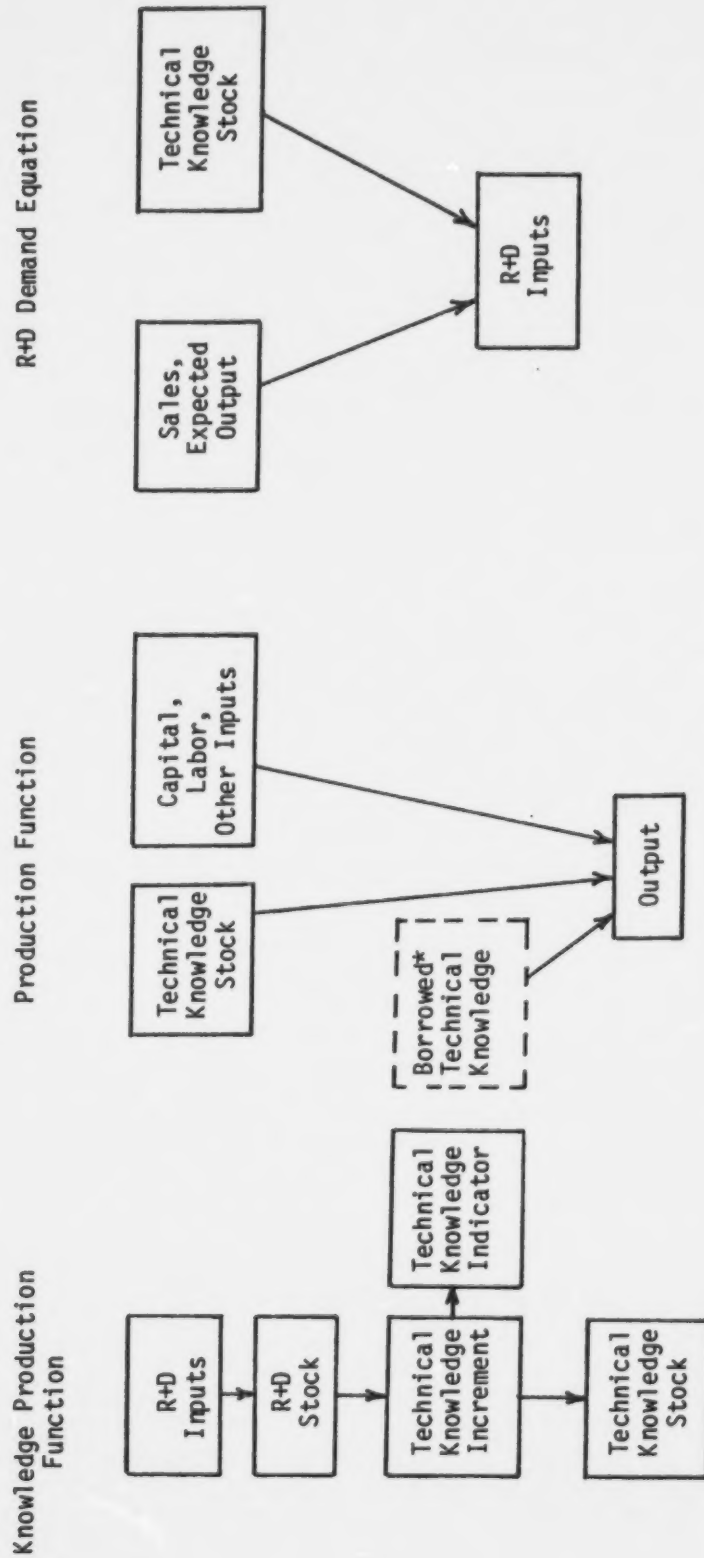
data can be obtained. It also provides a number of ways of modeling possible TSCA impacts at various stages of the innovation process. These approaches are discussed for each of the equations in the model. Figure 1-1 is a schematic model of the firm's research and production process which underlies the three equations.

The Knowledge Production Function

The left of Figure 1-1 shows the relation between R+D inputs and the creation of an "increment to knowledge" such as a new chemical entity (NCE) or new process. Increments to knowledge are not directly observable; however, patents, publications, or other such indicators may be useful proxies for innovation outputs. A given increment to knowledge typically results from R+D expenditures over a number of years. This process may be modeled using the concept of an R+D "stock" which summarizes the effect of expenditures over several years. In turn, increments to knowledge by the firm over a number of years may be considered to contribute to a "stock" of technical knowledge which affects its overall productivity.

The knowledge production function equation developed in this study relates measures of the R+D stock to the number of patent applications per year. The methodology used here follows that developed by Griliches, Schankerman and Pakes, among others. Rather than focusing on individual projects, we have attempted to develop an equation which describes the average relationship between a firm's R+D inputs and its innovation outputs. Given this structural relationship, TSCA impacts may be represented as an adjustment factor which reduces the average productivity

Figure 1-1
The Research and Production Process



*Not represented in our equations.

of the R+D stock or reduces the probability that a given innovation will be successfully achieved.

Production Function

The middle of Figure 1-1 shows the firm's output as a function of capital, labor, other material inputs, and the stock of technical knowledge described above. The knowledge stock is also unobservable, but may be measured by a proxy based on R+D expenditures or indicators of increments to technical knowledge. The knowledge stock is expected to "depreciate" in usefulness over time, faster for the individual firm than for the industry as a whole since the firm can lose its technological advantage to other firms. Similarly, the firm can borrow technical knowledge from other firms. The knowledge stock together with other factors contributes to total factor productivity. Total factor productivity is the amount of output produced by an average unit bundle of conventional physical inputs. The level of total factor productivity describes the amount of output that can be produced with given amount of conventional inputs. Treating the knowledge stock like another factor of production is equivalent to assuming that a firm can produce the same amount of output with fewer normal inputs if it has a greater stock of knowledge to rely on.

The specific functional form used is the Cobb-Douglas. Although this specification imposes some strong assumptions about the rates of substitution between factors, that issue is not a major concern of this analysis. We are mainly interested in the effects of the knowledge stock on output and in any changes in this relationship which might be attributed to TSCA.

This specification does entail a number of other simplifying assumptions, however. It does not take into account the changing mix of products which results from product innovation; the specification of the effect of the knowledge stock implies that the only kind of innovation is process change. It also does not specify that product innovation affects overall sales only through the growth of new chemical sales, not the sales of established commodity chemicals. The production function only captures the private gains of the firm; any benefits passed on to customers in the form of lower prices are not detected. In more general terms, the equation describes only the production function, but future sales can be estimated only by considering the joint effects of supply and demand. Nevertheless, increased sales and profits are the basic motivations to firms for conducting R+D, so it seems reasonable to expect to be able to identify a positive relationship between the two. Also, without access to confidential data it is not possible to identify the fraction of firm sales made up by new chemical products.

A more general problem with firm-level data is that large chemical firms typically produce in a variety of major industries. Therefore, it is generally impossible to identify relationships specific to the chemical industry.

TSCA impacts on output can be represented if it is predicted that TSCA leads to a change in the overall level of the knowledge stock or a change in the marginal productivity of the knowledge stock.

R+D Demand Equation

The R+D demand equation is the final element of the innovation model and closes the feedback loop by specifying that R+D expenditures (inputs to the knowledge production function) depend on firm's expectations of future sales growth which results from increases in the stock of knowledge via the two other equations. This is shown in the right-hand side of Figure 1-1.

Our formulation of the R+D equation is based on the assumption that the firm will invest in R+D up to the point at which the added present value of the benefits equals the added cost. Innovation is assumed to take the form of reductions in unit production costs, or the equivalent effect of new products. Benefits of these cost savings are assumed proportionate to total sales. The equation explicitly incorporates the specification of the knowledge production function. Two forms of the R+D demand equations are derived. In the first, R+D expenditures are given as a function of last year's R+D expenditures, current sales, and the anticipated growth rate of production. In the second, the intensity of R+D--R+D as a percentage of sales--is a function of last year's R+D intensity and the expected growth rate of production.

The specifications of the R+D demand equation include parameters for the firm's discount rate, the rate of depreciation of technical knowledge, and the gestation lag between innovation and benefits from cost reductions. The coefficients obtained from the empirical estimation can be tested to determine whether they imply reasonable values for these parameters.

The model has a number of simplifying assumptions. Firms are assumed to forecast correctly (except for a random error term) the growth rate of the future sales and the benefits accruing to them in all future periods resulting from current R+D efforts. Cost savings are assumed to be a constant fraction of price in each period.

The R+D demand equation incorporates the knowledge production function described in the previous section together with estimates of the gestation lag between innovation and the first returns from it, the rate of the decay of useful knowledge, the expected growth rate of sales and the discount rate. The knowledge production function reflects any changes in R+D productivity due to TSCA. The gestation lag can be adjusted to account for TSCA impacts which delay the introduction of new chemical entities to the market. The rate of depreciation of knowledge might also be adjusted downward to reflect a lessening of competitive pressure due to reduced R+D.

Data and Results

Introduction

This section describes the data used to estimate the three-equation model of innovation outlined above, the estimation results, and the interpretation and limitations of the results. The work presented thus far must be regarded as preliminary; proposals for further work are given in the last section. There are a number of limitations, including an over-aggregated and probably biased sample of the industry, reliance solely on patents as a measure of innovation output, and a number of estimation issues that remain to be resolved. Nevertheless, the results

are encouraging in that the estimated relations have a high statistical significance and the coefficient estimates imply reasonable values for important parameters in the theoretical models.

Data Sample

There are about 1,500 firms that produce chemicals and allied products*. Annual data were assembled initially for 80 publicly owned firms covering a twenty year period of interest, 1960-1980. Data availability and involvement in the chemical industry determined the selection of firms in the sample. Only publicly-owned firms were included because financial data on them can be obtained from sources such as annual reports and 10-K reports provided by the Securities and Exchange Commission (SEC). The sample of firms was compiled from several sources, including trade literature lists of major chemical firms and firms identified as belonging to the major chemical-related SIC groups. This selection procedure has biased the sample to large diversified firms, whose innovation behavior may differ significantly from that of smaller, more specialized firms. Also, the aggregate financial data used in this study includes activities by firms in a wide range of areas, cutting across many important strategic groups within the industry and including a number of areas outside the chemical industry. Therefore, differences in innovation across industrial groups are likely to be obscured.

Two main kinds of data are used in the analysis: firm financial data and measures of innovation, in this case, counts of patent applications. Financial data including sales revenue, R+D expenditures, capital expenditures

*SRI International 1979 Directory of Chemical Producers.

and employment were taken from firms' 10-K and annual reports. Value added data by four-digit SIC group were obtained from the Census of Manufacturers. Counts of chemical patent applications are from the data base of the U.S. Patent Office, Office of Technology Assessment and Forecasting (OTAF).

The initial estimation results were obtained for a sample of 48 out of the original 80 firms. These firms were chosen because they had relatively long and complete time series for the variables being analyzed. However, they cannot be considered a representative sample of the industry as a whole, so the results presented below must be considered preliminary, and further work is needed to expand the data base significantly.

Knowledge Production Function

The patent equation was fitted with the pooled time series data on the 48 firms described above. A number of different specifications of the R+D stock were tried, and the explanatory power of the different specifications was very similar and quite strong. The data supported (or at least did not reject) the hypothesis that all firms have the same elasticity of patenting with respect to their R+D stock, i.e., an equal percent change in the R+D stock leads to an equal percent change in the number of patent applications. Estimates of the value of the elasticity range from 0.37 to 0.48. The data did not support the hypothesis that all firms have the same average productivity of their R+D stocks; indeed, inter-firm variations in R+D productivity appear to be a strong determinant of patenting behavior. This may be explained partly by differing "propensities to patent" of different companies.

Production Function

The production function was fitted using the log-log form of the Cobb-Douglas equation. A number of different specifications of firms' capital stocks and knowledge stocks were tried, with little evident difference among them. Results are presented for two specifications, one where the R+D stock is defined as having an inverted-V structure of weights for R+D expenditures over the previous five years, and one where the R+D stock is defined as a depreciated sum with a 20 percent per year depreciation rate.

The results of the two equations are very similar, both for the range of constant terms and the elasticity coefficients. The R-squares are high, and all the elasticity coefficients are significant and have reasonable magnitudes. The values for the elasticity of output with respect to the R+D stock are high relative (about twice as large) to those obtained in an unpublished study by Griliches and Mairesse using a similar model. As in the case of the patent equation, it would appear that inter-firm rather than intra-firm variation contributes the bulk of the explanatory process of the equation.

Tests were performed in which the intercept is restricted to a single value for all firms and which different values of the elasticity coefficients are allowed for different firms. The results indicate that average inter-firm differences are important, as reflected in the constant term, but differences in the elasticities are not, or at least are not detectable given this data. Tests were also performed restricting the production function to constant returns to scale in capital and labor and constant returns to scale in capital, labor, and the R+D stock. In

general, the hypotheses implied by these joint restrictions were rejected. The production function was also fit using different R+D elasticity coefficients for different groups of firms. The firms were grouped in accordance with their primary SIC group. These results were not significant either.

R+D Demand Equation

The R+D equation is derived from the relation of R+D to the production of technical knowledge and the subsequent influence of that knowledge on sales. The formal derivation of the equation used in our regressions is given in Appendix E. Two forms of the R+D equation were used. The first corresponds to a lagged adjustment model in which R+D at the firm level adjusts over time to the desired or optimal firm level. In the second formulation, the adjustment is assumed to take place between the actual and desired level of R+D intensity, where R+D intensity is defined as the ratio of R+D to sales. The right-hand variables are R+D expenditures in the previous year, the firm's expected rate of growth of future production, and current year sales.

The expected growth rate variable is not observable. In our estimates of the R+D equation we used a surrogate the actual growth rate of production over the next year as a surrogate for the expected growth rate. This assumes that the firm has so-called "rational expectations" and can forecast its growth with an error whose average value over time is zero. The expected rate of growth in production is thus a true value plus an error term. This produces the errors-in-variables problem often encountered in regression analysis. Consequently, an ordinary least squares regression will produce a biased estimate of the coefficient of

the growth rate. For this reason we use instrumental variables in the estimation of the equation to obtain an estimate of the growth rate whose error term is uncorrelated with R+D expenditures.

The first equation has a very high R-squared, which should not be surprising, given the use of firm-specific constant terms and the typically high degree of correlation of R+D expenditures with lagged R+D expenditures and sales, as is reflected in the high significance of their respective coefficients. These results do not imply much support for any particular model of R+D demand. The growth rate term is not statistically significant in this estimate.

The second equation shows R+D intensity as a function of the expected growth rate and lagged R+D intensity. It has a good fit for similar reasons. In this specification, the coefficient of the expected growth term is strongly significant. Further investigation is needed to determine why this different result occurs.

The coefficient estimates of the R+D intensity equation are shown to imply reasonable values for the parameters of the underlying theoretical model. This lends greater credibility to the model, and, in particular, makes it more plausible to use the model to simulate TSCA impacts by altering the values of the parameters in ways that TSCA is assumed to affect them to see the resulting impact on the demand R+D.

Using the Innovation Relationship

We have used the intensity form of the R+D equation estimated in the previous section to forecast industry-wide levels of R+D intensity using data for the National Science Foundation categories "Industrial Chemicals"

and "Other Chemicals" and two alternative industry forecasts made by Data Resources, Inc. (DRI). These forecasts are baseline in that they do not include any predicted TSCA effects.

First, the R+D equation is used to generate values of R+D intensity using historical values of the right-hand side variables, lagged R+D intensity from the NSF data base and the actual growth in industry production as reported in the DRI chemical production index. The predicted values of R+D intensity are shown to track the actual ones fairly closely. The standard deviation of the differences between the actual and predicted values of R+D intensity for the period 1971-80 is .118 or 4.1 percent of the average value of 2.88 for R+D intensity. Almost all of the turns in actual R+D intensity also occur in predicted R+D intensity.

Second, values of R+D intensity from 1980 to 1990 are predicted using the predicted values of the right-hand variables taken from the two DRI forecasts. The growth rate of production is taken directly from the forecasts. Lagged R+D intensity is simply the value predicted by the R+D equation for the previous period. The first forecast is DRI's "Trendlong" projection which assumes steady long-term economic growth without major fluctuations. The other DRI forecast is the "Cyclelong" projection which assumes significant fluctuations in economic growth due to business cycles or periodic shocks. The "Trendlong" forecast of R+D intensity stays close to the value of 2.5 percent, while the "Cyclelong" forecast

fluctuates between 2.6 and 2.2 percent. Of course, the error of the forecast increases with its distance into the future.

Future Research

The formulation and estimation of the patent equation, production function, and R+D equation were guided and constrained by the current information regarding TSCA. Our aim was to construct a baseline and a model with which TSCA regulatory actions can be assessed. Because the mandate of TSCA is broad, those future actions may take a number of forms, e.g., the banning of a group of chemicals. Without specific information regarding the TSCA action, it is impossible to formulate a baseline model that links the regulatory actions to useful innovation indicators of the chemicals industry.

Our research was also guided and constrained by the chemicals industry data that are available. We used a firm-level approach because there are data available on R+D expenditures for publicly owned firms and we employed patent counts as an innovation indicator because the data are available from the Office of Technology Assessment and Forecasting.

The modeling work described in the previous sections has provided a promising beginning but a good deal of further work needs to be done to develop a model with a sufficiently good data base and level of disaggregation to provide a basis for analyzing TSCA impacts. Further work along three major lines is proposed:

- 1) Data Collection Effort: This includes increasing the coverage of the data set to include smaller firms, obtaining chemical line financial data for large diversified firms, obtaining additional measures of innovation outputs, and obtaining separate estimates

of product and process innovation. A survey may be included in this effort;

- 2) Modeling Effort: This includes refining the existing three equation model, e.g., identifying different behavioral patterns among different segments of the industry, and developing a model which includes the choice between product and process innovation; and
- 3) Impact Methodology: Develop a methodology to determine aggregate industry impacts and use the model in simulation exercises to predict TSCA impacts using the TSCA-related parameters identified in the model.

Section 2

Introduction

Goals

The goal of this project is to provide the means whereby EPA can estimate the impacts of the Toxic Substances Control Act (TSCA) on the chemicals industry and on the national economy. If this capability is developed, EPA will be better able to track the effects of regulatory actions for the purpose of correcting those that have caused too severe adverse effects relative to their benefits and defending other actions that may be unjustifiably blamed for such effects. These estimates will provide a useful comparison with other studies of estimated TSCA impacts. In addition, EPA will be better able to plan and evaluate future regulatory options before they are promulgated.

Project Objectives

The objective of the research work to date is a methodology to produce a baseline forecast against which the effects of TSCA actions can be measured and a model which provides a framework to estimate the impacts on the baseline variables. The baseline consists of a set of variables that describe conditions in the chemicals industry--such as rate of innovation, sales, profits and other measures of business performance--in the absence of TSCA regulation.* The model describes the behavioral relationships

*Effects of TSCA may have occurred prior to promulgation of any regulation, or even prior to the October 1976 enabling legislation, if firms behaved differently in anticipation of changes they assumed would come about. For example, it would not be surprising to learn that firms hastened (or delayed) their normal course of action to develop or commercialize specific new chemicals during 1976-1980, as they perceived EPA's efforts to implement TSCA.

which are identified among the baselines variables and allows the effects of TSCA impacts to be traced out.

There is general agreement that TSCA is most likely directly to affect those activities in the chemicals industry that relate to innovation; the activities include research, development, testing, and commercialization of new products and processes. If a firm's innovation activities are influenced by TSCA, then eventually sales, profits, employment and other measures of industry performance will be affected. Therefore, it is desirable to relate changes in innovation activities to changes in business performance at the firm level and at the industry sector level. At the outset of this project, the baseline was envisioned as including a broad range of business performance measures that would serve as useful indicators* if they could be linked to innovation variables. However, causal factors other than TSCA regulation linked to innovation-directed activities will affect business performance of the chemical industry; these include other health related regulations (OSHA, CPSC, etc.), feedstock prices, consumer demands, foreign competition, the state of national economy and so forth. Such factors are likely to have a much greater effect than TSCA regulations and we believe it will be very difficult, perhaps impossible, to isolate the incremental changes in business performance due to TSCA.

For the above reasons, development of a useful set of relationships that explain innovation--an innovation model or models--is the first priority before serious effort is made to link innovation activities to business

*e.g., industry sales, value added, total costs, employment, wages, investment in plant and equipment, capacity, capacity utilization, chemical price index, profitability, productivity, balance of trade.

performance. Hence the research described in this report has concentrated on the development of baseline variables which relate in a direct way to innovation activities (e.g. number and value of new chemicals, R+D expenditures), and on development of an analytic method and data base that can be used to estimate the baseline variables.

Study Approach

Our approach was first to consider several kinds of analytical models for describing innovation. The approaches can be divided into two major kinds of models: those that address individual innovations and those that treat aggregations of innovations or other inputs and outputs at the firm, industry segment, or industry level. The aggregate innovation model approach was then selected as the basis for deriving and testing a structure for an explanatory model of innovation. The selection was based in large part on data requirements and on our desire to use publicly available data for the early work. In addition, the aggregate approach focuses on the overall average performance of innovation activity in the industry and the corresponding average impacts of TSCA, rather than focusing on individual cases which may not be representative of the industry. However, we are aware that other data might be acquired at a later date by a survey of the chemicals industry. When the study project was initiated, an industry survey was anticipated as part of the work under the assumption that a preferred methodology for generating a baseline could be selected relatively quickly, i.e., within the first few months. The data needs for the preferred methodology would have guided the design of a survey to acquire missing information needed for the approach. The assumption was later abandoned and the research work was

continued, using only publicly available data. (The design and conduct of the survey remain for future work that may be carried on by EPA to further develop the innovation model and the baseline estimates.)

Project Outputs

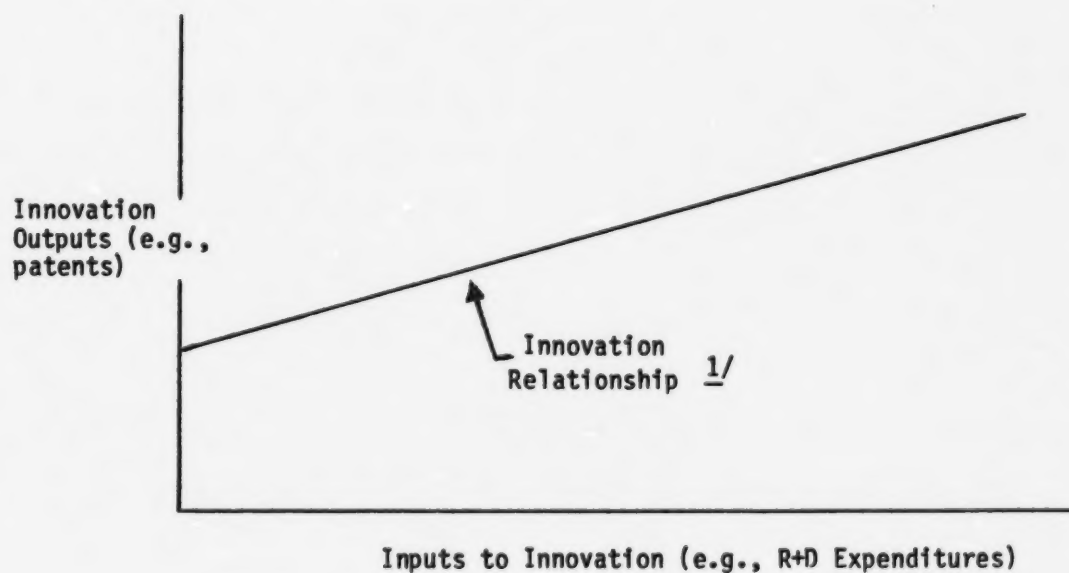
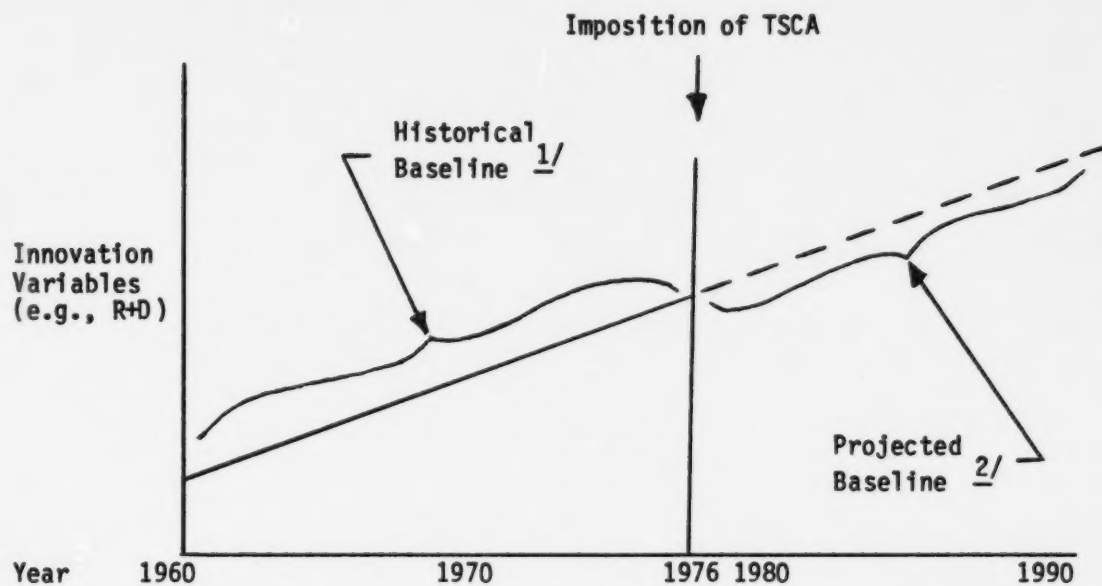
The primary outputs sought from the selected approach are historical data relating to innovation variables and a model (or models) that depict relationships among those variables. These elements can be used in a number of different ways. The model can be used to project values of the baseline variables for future years. These projections can be compared either with the observed values of these variables (ex post analysis) or with alternative projections of baseline variables generated by adjusting the coefficients of the model to reflect estimates of TSCA impacts (ex ante analysis). These approaches are discussed in greater detail below. It will be seen that the difficulty of attributing ex post differences between projected and actual values to specific TSCA impacts rather than other forecast errors suggests that ex ante analysis may provide more reliable impact estimates.

Figure 2-1 illustrates some of these types of outputs in terms of two graphs. The top graph shows innovation variables over time and the bottom graph shows an innovation measure versus an input to innovation, e.g., R+D expenditures. One of the primary outputs of the study is the historical record of innovation variables, such as number of new chemical entities (NCE), number of patents, etc.--the "historical baseline" of the top graph. The other primary output, an innovation model (a set of relationships among the historical data), is illustrated by the bottom graph where an innovation measure is related to R+D expenditures. A

Figure 2-1. Project Outputs

1/ $\equiv$ Primary Output

2/ $\equiv$ Secondary Output



secondary output is the set of projected values of the baseline variables. The projections of those values rely on extrapolations of historical trends and on the innovation model.

As mentioned earlier, TSCA dates from October 1976. However, there have been relatively few regulatory actions to date. Accordingly, EPA views the project as a first step in developing useful methods for monitoring the progress of the industry over time. This orientation emphasizes the use of the data and models for ex post analysis instead of for ex ante projections. Development of the primary outputs--the innovation historical baseline and the innovation model--will be useful for ex post analysis of the effects of TSCA on the chemicals industry. By comparing the historical baseline with data acquired in the post-TSCA period, changes in variables, such as the rate of new chemical introduction or R&D expenditures, can be monitored. The innovation model will help in separating those changes that can be attributed to TSCA actions from changes that would have occurred anyway.

However, such an ex post approach faces difficult problems because of the many other factors that may have changed between the time the forecast is made and the time the actual values are observed. A prime example of this is the 1962 Kefauver-Harris amendments to regulations governing the pharmaceuticals industry. Despite a significant drop in the number of NCE's observed after 1982 and a sharp rise in their average costs, there is still much controversy about the relative roles of the amendments and other factors such as depletion of research opportunities. In general, any empirical attempt to link deviations of observed values from predicted values with specific TSCA impacts will be tenuous because of forecast error.

An approach which avoids this problem is ex ante analysis. The general approach would be to start with a baseline forecast of innovation variables and an exogenous estimate of direct TSCA impacts for an "average" project in terms of, say, added R+D costs, time delay, or reduced probability of success for each NCE. The innovation model developed in this study would then be used to trace the effect of these impacts on the important innovation variables, such as the number of NCE's per dollar of R+D expenditures, the level of R+D expenditures, and the contribution of R+D to productivity growth. The analysis could be performed separately for behaviorally distinct segments of the industry, then aggregated to the industry level based on the composition of the industry. The impact would be identified as the deviation of the innovation variables from their baseline values. In effect, the procedure is an "experiment" which perturbs the innovation model in a way which is believed to represent the effect of TSCA regulations. This approach eliminates the need to compare predicted and actual values, but its credibility depends both on the validity of the model and on the simulation of TSCA impacts.

Industry Scope

The industries of particular interest to EPA are those which produce and/or use chemicals, including petrochemicals. More specifically, EPA has used the Standard Industrial Classification (SIC) Codes to identify affected firms. All firms classified as belonging to SIC group 28 (Chemical and Allied Products) (except those that manufacture pesticides or drugs) are included in the study. Within SIC Group 29 (Petroleum Refining and Related Industries), only petroleum refining is included in

the study. The industry sectors within SIC groups 28 and 29 that are included are listed in Table 1.

Project Organization and Execution

The research effort was originally defined by EPA in the Statement of Work (Contract No. 68-01-6134 Exhibit A, May 7, 1979). The effort was defined in four phases of which this project was concerned with the first two. The four phases are (1) project initiation (2) development of baseline scenario (without TSCA), (3) impact analysis and (4) summary of economic impacts.

The effective start date on the first two phases was September 1980. Meta Systems Inc is the prime contractor and has worked with two subcontractors, Data Resources, Inc. and Charles River Associates, Inc. Data Resources made a preliminary assessment of national economy and chemical industry baseline variables that could be estimated by using their current computerized models and information services. Charles River Associates investigated different approaches for modeling innovation in the early part of the project.

Dr. Mark Schankerman of New York University participated as a consultant to Meta Systems on the innovation modeling work. His suggestions on concepts, use of data, and interpretation of results were of great assistance to Meta Systems.

We also acknowledge the contribution of Dr. Christopher T. Hill of the Massachusetts Institute of Technology and Dr. Edwin Mansfield of the University of Pennsylvania. Dr. Hill's suggestions helped greatly in clarifying project research objectives and priorities and also in

Table 2-1
Industrial Sectors Included in Project Scope

- 28 Chemicals + Allied Products
 - 281 Industrial Inorganic Chemicals
 - 2812 Alkalies and Chlorine
 - 2813 Industrial Gases
 - 2816 Inorganic Pigments
 - 2819 Industrial Inorganics NEC
 - 282 Plastic Materials and Synthetic Resins, Rubber, Other Fibers, Except Glass
 - 2821 Plastic Materials, Synthetic Resins and Non-Vulcanized Elastomers
 - 2822 Synthetic Rubber
 - 2823 Cellulosic Man-Made Fibers
 - 2824 Synthetic Organic Fibers, except Cellulosic
 - 284 Soaps, Detergents, Cleaning Preparations, Perfumes, Cosmetics, Toilet Preparations
 - 2841 Soap and Other Detergents, Except Specialty Cleaners
 - 2842 Specialty Cleaning, Polishing and Sanitation Preparations
 - 2843 Surface Active Agents, Finishing Agents, Sulfonated Oils and Assistants
 - 2844 Perfumes, Cosmetics and Other Toilet Preparations
 - 285 Paints, Varnishes, Lacquers, Enamels and Allied Products
 - 2851 (Same description as 285)
 - 286 Industrial Organic Chemicals
 - 2861 Gum + Wood Chemicals
 - 2865 Cyclic (Coal Tar) Crudes, Cyclic Intermediates, Dyes and Organic Pigments
 - 2869 Industrial Organics NEC
 - 287 Agricultural Chemicals
 - 2873 Nitrogenous Fertilizers
 - 2874 Phosphatic Fertilizers
 - 2875 Fertilizers, Mixing Only
 - 289 Miscellaneous Chemical Products
 - 2891 Adhesives and Sealants
 - 2892 Explosives
 - 2893 Printing Ink
 - 2895 Carbon Black
 - 2899 Chemicals and Chemical Products NEC
- 29 Petroleum
 - 291 Petroleum Refining
 - 2911 (same description as 291)

identifying important issues to be addressed in any future survey of the chemicals industry. Dr. Mansfield served as a critic of several working papers and made useful suggestions about various modeling approaches and sources of data on innovation. However, Meta Systems is solely responsible for the project work reported here.

Report Organization

Section 3 describes the data and the different analytic approaches for an innovation model that were considered before adopting the selected approach. These include the rate of return methodology and various approaches used to analyze the 1962 Kefauver-Harris drug amendments. Difficulties and limitations of each are discussed. Section 4 describes the theoretical basis of the three equation model of innovation that has been adopted for this study. The three equations are a technical knowledge production function, a production function which links a firm's output to its inputs, including a stock of technical knowledge, and an R+D demand equation. The discussion of each equation includes ways to model TSCA impacts.

Section 5 describes the data and some preliminary estimation results for the three fundamental equations that constitute the innovation model. The first part of Section 5 describes the data sources used and the reasons for selecting the data sample used. The remaining three parts of Section 5 present the estimation results for the three equations together with discussions of their limitations and some preliminary examples of the effects of TSCA impacts.

Section 6 discusses some possible uses of the model results and presents the results of a simple simulation exercise to forecast R+D intensity in the industry. Section 7 discusses and recommends future work needed to develop the methodology and baseline so that it can be used operationally by EPA. This work includes: more intensive data collection, including possibly a survey; refinements of existing equations; implementation of the impact methodology; and development of a model which accounts for the choice between product and process innovation.

A number of appendices are included as well. Appendix A is the bibliography. Appendix B discusses and evaluates various approaches to classifying the industry into segments with important behavioral differences. Appendix C summarizes the most important data sources and data items available. Appendix D contains several book reviews of studies of the 1962 drug amendments whose major points are discussed in Section 3. Appendix E gives the theoretical derivation of the R+D demand equation presented in Section 4. Appendix F provides a brief description of the proposed product/process model of innovation.

Section 3

Review of Literature and Evaluation of Methodological Approaches

Introduction

This section includes a review of the literature relevant to analyzing the impacts of TSCA regulations on the chemical industry and a review of alternative methodological approaches which led up to the adoption of the multi-equation model described in Section 4. The literature contains two major approaches to modeling innovation: case studies and aggregate analyses of variables such as R+D expenditure and the production of new chemical entities at the company or 4-digit SIC level.

The case study approach is represented by the rate of return methodology pioneered by Mansfield and others to measure the private and social returns of individual R+D projects. In theory, the approach is to calculate the return on the project based on all identifiable costs and benefits associated with the project. In practice, this procedure has massive requirements for confidential data, making the sample available to the researchers very dependent on the cooperativeness of firms. Using this approach to estimate impacts for the industry as a whole also entails a number of problems. The second section of this chapter reviews and evaluates this literature.

Aggregative approaches to the analysis of innovation are more varied. In terms of their effect on innovation, the 1962 Kefauver-Harris amendments to regulations covering the pharmaceuticals industry may be the regulatory "event" which provides the closest precedent for TSCA regulations, although there are important differences as well. Therefore,

the literature which attempts to assess the impact of the 1962 amendments is a fruitful source of approaches for this study. The third section surveys this literature, evaluates the strengths and weaknesses of the various models, and draws conclusions about their applicability for the TSCA study.

Another aggregative method was proposed by our subcontractor, Charles River Associates, and is described in the fourth section. Although it shares many features with the methodology eventually adopted, it was not adopted because of its lack of differentiation of different phases of the innovation process.

The final methodology described in Section 4 is based on the approach employed by Schankerman, Griliches, Pakes and others to analyze the innovation process as the use of inputs to produce a stock of "knowledge" which in turn acts as an input to a firm's normal production function together with capital, labor, and other inputs.

Rate of Return Methodology

Description

Many researchers have attempted to measure the innovative performance of firms and industries by using the rate of return (ROR) approach.*

*Mansfield et al., The Production and Application of New Industrial Technology, Norton, 1978, Chapters 8 and 9.

Mansfield et al., "Social and Private Returns from Industrial Innovation," Quarterly Journal of Economics (May 1977): 221-240.

Tewksbury et al., "Measuring the Societal Benefits of Innovation," Science, August 8, 1980, p. 658-662. This article is based on Foster Associates, "A Survey on Net Rates of Return on Innovations," Report to the National Science Foundation, May 1978.

Robert R. Nathan Associates, "Net Rates of Return on Innovation," Report to the National Science Foundation, October 1978.

Basically, this rate of return approach attempts to compute the private and social benefits of specific innovations. Private returns to innovation are defined to include the profits accruing to the innovator above and beyond the profit foregone on displaced products. Social returns to innovation include four items: the private returns just described; the net financial returns to imitators; an adjustment factor for any external costs; and the savings accruing to customers from price reductions.

The researchers measure the costs and the revenues attributed to each innovation, then discount the annual cash flows to obtain an "internal rate of return." By this method, the internal rate of return is the measure of innovative performance. Tewksbury et al. list the many steps required to measure these rates of return (page 659). Mansfield et al. (1978, pages 146 to 156) describe in detail the procedure followed.

Data Requirements

The data requirements for this analysis are extensive, very detailed and, in some cases, necessitate access to confidential company data. Table 3-1 lists the data items needed to measure the returns to innovation. The check marks on the table indicate which data items are used for the four identified components of social and private returns.

Mansfield (1977 and 1978), Tewksbury (1980), and Nathan (1978) have mentioned the difficulty of obtaining data from the firms:

Table 3-1
Data Requirements for Estimating Rates of Return to Innovation

Date Item	Social Returns			
	Price Savings to Customers	Resource Savings:		Private Returns:
		(External Costs)	Net Profits to Imitators	Net Profits to Innovators
Name and function of the innovation	X	X	X	X
Name and function of displaced product or process	X	X	X	X
Gross profits to innovator from the innovation over the years				X
Cannibalized profits on all displaced products from all manufacturers (if any) over the years			X	X
Gross profits to imitators from the innovation, if any, over the years			X	
External costs imposed by the innovation, if any (EPA, OSHA...) over the years		X		
External costs imposed by the displaced products, if any (EPA, OSHA...)		X		
Price level or index for innovation and displaced products over the years (after and before innovation)	X		X	X

Table 3-1 (continued)
Data Requirements for Estimating Rates of Return to Innovation

Date	Item	Social Returns		
		Price Savings to Customers	Resource Savings: Net Profits to Imitators (External Costs)	Private Returns: Net Profits to Innovators
	Quantity sold of new products	X		
	R+D costs for the specific innovation		X	X
	Other investment costs directly related to the innovation		X	X
	Price elasticity of demand for the innovative product	X		
	Proportion of successful to non-successful R+D projects for the specific company or adjustment factor for uncommercialized R+D projects		X	X
	Price index for the chemical industry plant and equipment		X	X
	Production scale of innovation over time	X	X	X

"As would be expected, a substantial percentage of those that were contacted refused to cooperate because, despite an assurance that the data would be held in strict confidence, they felt that such data were too sensitive to show outsiders." (Mansfield, 1978, page 145)

"As a practical matter, however, even though information was sought on a confidential basis, it was so difficult to obtain that availability of data became dominant in the selection of cases." (Tewksbury, 1980, page 658)

"[Selecting suitable innovations] proved to be an exceedingly time consuming and frustrating task." (Nathan, 1978, Executive Summary, page 3).

However, Tewksbury, et al. mentioned that for 9 of the 20 innovations they studied, data were "taken primarily from published sources." Five of these 20 innovations came from the chemical industry: the article does not indicate if data for the 5 chemical innovations came primarily from public or private sources.

Nathan (1980, pages 9 and 11) points to other measurement problems. He indicates that for integrated or regulated firms, prices may not correctly reflect the market value of the products or processes. Concurring with Mansfield, he points out the model cannot be applied to major new products (automobiles, televisions, computers) that perform functions quite different from the products they displace. Finally, Nathan indicates that improvements in consumer products cannot adequately be measured by cost savings, and that in certain cases, multiple social and economic impacts make the approach unmanageable.

The Contribution of Other Factors

Implicitly the ROR approach attributes all the returns to the innovation itself. Any returns over and above costs are assumed to have

been exclusively caused by the innovation itself, rather than in conjunction with other potential causes, such as scale economies, unexpected increases in demand, better management techniques or specific inflationary forces. Attributing these returns specifically to innovation may distort considerably the innovation process in general and of the chemical industry in particular.* If using this approach implicitly overestimates the true private returns to innovation, then policy makers may be misled to think that additional costs and delays imposed by regulations will have a benign effect.

The importance of correctly attributing the return to the many factors causing these returns is underscored in a book written by Edward Denison.** In his book, Denison identified and quantified close to 20 sources contributing to the growth in the U.S. national income. Two of the factors he identified are of direct importance to the TSCA project: advances in knowledge and economies of scale. Overall, for the U.S. economy Denison estimated that scale economies were equivalent to about one-third of the contribution by advances in knowledge. We may assume that the proportion is higher in the chemical industry for two reasons. One, the chemical industry is process-intensive and scale economies are very important: for each doubling of production volume, unit costs fall by more than 30 percent, following the Rule of the Two-Thirds.*** Second, Denison's estimate of

*Nathan agrees with this point, but does not modify the methodology to take these other factors into consideration (Nathan, 1978, page 7).

**E. F. Denison, Accounting for United States Economic Growth, 1929-1969, Brookings Institution, 1974. See also, J. W. Kendrick, Postwar Productivity Trends in the United States, 1949-1969, National Bureau of Economic Research, General Series 98, 1973.

***This rule of thumb used by process engineers states that while volume expansion follows a cubic progression, equipment costs only increase by a square factor. Thus yield increases faster than equipment costs.

the contribution of advances in knowledge to growth includes the residual amount of variation in growth which was not explained by the other factors he identified. This residual cannot necessarily be associated with specific innovation behavior. Thus, for these two reasons, scale economies could represent as much as half, or possibly more, of the contribution of advances in knowledge in the chemical industry. As a crude adjustment, financial returns or price reduction due to larger production scales could be first deducted from total returns. After other adjustments, if any, are made, the residual would be attributed to the innovative activity.

Using Other Indices for Profitability of Chemical Innovation

Rates of return can easily be compared with benchmarks or among themselves. But rates of return do not indicate the absolute magnitude of the various R+D projects, of the subsequent innovations, and of the private and social benefits. Presumably, the costs imposed by TSCA regulations will not vary directly with the size or the profitability of the project. These TSCA costs (expressed in dollars or delay period) will probably vary little between projects. The total TSCA costs may even vary less than proportionately with the number of projects undertaken by any single firm. Therefore, in addition to private rates of return, and in order to have a preliminary assessment of the impact of TSCA, we need to have indicators of the relative size of the projects, and perhaps of the numbers of projects by firm.

Conclusions

The ROR methodology is not adopted because of its extensive requirements of confidential data. Even if data for a large sample of case studies could be obtained, it would be difficult to determine whether this sample is representative of the industry and how an analysis of TSCA impacts for this sample could be extrapolated to the industry as a whole.

Review of Drug Industry Literature

Studies of the effect of the 1962 Kefauver-Harris amendments on the pharmaceuticals industry were reviewed to identify methods and variables relevant to the measurement of innovation and also to see if different impacts (different in degree or type) observed among different pharmaceutical firms might suggest useful methods for identifying appropriate aggregations of chemicals firms. This review discusses the strengths and weaknesses of the individual studies.

Three pharmaceutical studies were reviewed in detail and evaluated for their usefulness in the economic analysis of the impact of TSCA on innovation in the chemicals industry:

- 1) David Schwartzman's The Expected Return from Pharmaceutical Research: Sources of New Drugs and the Profitability of R&D Investment, American Enterprise Institute: Washington, D.C., 1975.
- 2) Martin N. Baily's "Research and Development Costs and Returns: The U.S. Pharmaceutical Industry", Journal of Political Economy, 80, (1), January/February 1972, pp. 70-85.
- 3) Sam Peltzman's Regulation of Pharmaceutical Innovation, The 1962 Amendments, American Enterprise Institute: Washington, D.C., 1974.

We also looked at several other studies of the 1962 drug amendment:

- 1) James Jondrow's A Measure of the Monetary Benefits and Costs to Consumers of the Regulation of Prescription Drug Effectiveness, Microfilm, Madison, Wisconsin, 1972.
- 2) H. Grabowski, J. Vernon and L. Thomas's "Estimating the Effects of Regulation on Innovation: An International Comparative Analysis of the Pharmaceutical Industry", The Journal of Law and Economics XXI, (1), April 1978, pp. 133-163.

These studies are evaluated with respect to four main points: the independent and dependent variables considered; classification of firms into strategic groups; the models of innovation used; and the methodology used to assess impacts of 1962 amendments together with the results of the analyses. Detailed reviews of each study are given in Appendix D.

Innovation Variables and Models

The two most relevant methodologies resulting from the drug studies are Peltzman's drug innovation model in his cost-benefit analysis of the 1962 amendments and Bailly's R+D production function approach to new drug development.

Peltzman's demand-pull model of drug innovation is expressed as the following:

$$n_t = f(X, P, N_{t-1})$$

where: n_t = number of new chemical entities introduced in year t

X = three-year moving average of total number of out-of-hospital prescriptions sold

P = three year moving average of personal consumption expenditures on physicians' services

N_{t-1} = cumulative number of new chemical entities introduced in year $t-1$

In Peltzman's model the number of new chemical entities is a lagged response to changes in the demand side variables; the model fails to account for the supply-side factors which may affect the dependent variable, except possibly the depletion of research opportunities, which may be reflected in the N_{t-1} term. Other demand-side variables which might be considered are the growth rates of sales and profits.

Baily's R+D production function approach measures the number of new chemical entities developed in the drug industry in the following equation:

$$N_t/E_t = f(D, P)$$

where:

- N_t = number of new chemical entities introduced and discovered by U.S. firms in year t
- E_t = average deflated R+D expenditure in the U.S. in years $t-4$, $t-5$ and $t-6$
- D = effect of 1962 regulation, equal to 0 through 1961 and 1 after 1961
- P = measure of depletion of research opportunities taken as a 7-year moving average of past total new drug introductions.

In his supply-side model Baily measures the number of new chemical entities as a function of lagged R+D expenditures and the effects of regulation and the depletion of research opportunities over time. In contrast to Peltzman's approach, Baily recognizes only supply-side factors. Yet Baily does attempt to separate the regulatory factor from other supply-side factors--specifically, the depletion variable. The limitations of Baily's model include the following elements. First, Baily assumes a fixed-five-year lag between R+D expenditures and the introduction of new chemical entities. Second, he assigns a 7-year moving

average for the depletion variable without allowing for additions to the stock of knowledge.

Schwartzman performs detailed calculations to estimate rates of return to drug innovation, using industrywide figures and averages from various sources. The approach does not yield an explicit model of innovation.

We rank the study by Grabowski, Vernon, and Thomas* at the top of the literature we reviewed in the rigor of its methodology and the persuasiveness of its findings. Its methodology, an international comparative analysis of changes in R+D productivity in the same industry, is not suitable for our study at this time, however, because its use requires data on innovation performance for a minimum of five years after the regulation has been adopted.** The application of the methodology to our study requires that we identify another country whose chemical industry faces the same conditions of demand and supply as the U.S. chemical industry and where the trends and developments in the foreign industry during the period after adoption of TSCA in the U.S. match what trends and developments in the U.S. would have been in the absence of TSCA. Finally, the study by Grabowski et al. does not examine changes in process innovations and, therefore, cannot detect a possible shift from product to process innovations following the 1962 drug amendments.

Despite these imperfections, however, the study is an impressive one whose conclusion, that the 1962 drug amendments lowered significantly the

*Grabowski, Henry G., Vernon, John M., and Thomas, Lacy G., "Estimating The Effects of Regulation on Innovation: An International Comparative Analysis of the Pharmaceutical Industry", The Journal of Law and Economics, XXI, (1), April 1978.

**In anticipation of the eventual application of such a methodology, EPA may want to collect and monitor relevant data on innovation inputs and outputs as they become available.

productivity of the R+D resources of U.S. pharmaceutical firms in generating new chemical entities, must be given substantial weight.

Significant Company Groupings

None of the studies we reviewed attempts to delineate strategic groups of drug manufacturers or to test for different effects of the 1962 amendments on different types of drug manufacturers.

Impact Methodology and Results

The drug studies cited measure the effects of the 1962 amendments by means of two approaches: the production function and the rate of return approach. Major constraints faced by authors of the reviewed drug studies in their evaluation of the effects of the amendments during the post-1962 period were the limited gestation period and the lagged effects of the regulation on the ethical drug industry.

Peltzman's demand-pull model measures pre- and post-amendment new chemical entities using drug market growth data. Peltzman attributes the average post-'62 lagged drug market growth rate and resulting decline in drug innovation through the year 1971 to the 1962 amendments. He uses the flow of NCE's during the period 1948-62 to estimate innovation in the post-62 period without the 1962 amendments. The difference between the "predicted" and actual flows of NCE's after 1962 is attributed to the 1962 amendments. Peltzman fails to isolate the regulatory effects by assigning this difference to the amendments, when in actuality, as held by Grabowski, Vernon and Thomas (p. 141), "...this residual difference can plausibly reflect the effects of a number of other factors...(research depletion, changing expectations, and scientific factors), it probably encompasses various non-regulatory phenomena as well."

Baily's estimates from his production function approach measure pre- and post-regulation periods yet do not show any variation in the effects of regulation on innovation over time because he uses a simple dummy variable to distinguish the two periods. Simultaneously, Baily's estimates of expected financial returns to R+D are limited to the years 1954-1963 and, therefore, fail to measure any real effects of the 1962 amendments.

Schwartzman's estimates of the expected rate of return to pharmaceutical R+D show a pre-amendment value of 11.4 percent for the year 1960, a negative value for 1967, and a rising value of 3.3 percent for 1973.

Conclusions

ICF's September 1980 report, the "Economic Impact Analysis of Proposed Section 5 Notice Requirements" addresses the issue of the usefulness of empirical studies of innovation, and more specifically the usefulness of the extensive studies on the impact of the 1962 Amendments on innovation in the pharmaceutical industry. The report concludes that the drug studies "highlight some areas of interest to TSCA," but that the majority of the literature is not very useful. Generally, the drug studies are data constrained, post hoc, single equation analyses dealing with very different regulatory requirements. All these factors are not particularly helpful in an evaluation of TSCA's effects on the chemicals industry. Nevertheless, they do provide a helpful starting point by focusing on the relationships between R+D expenditures, measures of innovation such as new chemical entities, demand-side factors such as expected sales growth, and supply-side factors such as the depletion of research opportunities. If nothing else, they highlight the difficulty of associating a particular

impact with a particular government regulation, even though the impact itself is quite dramatic.

Reduced Form Equation

Charles River Associates, the subcontractor, formulated an approach relating measures of innovation performance to variables that are likely to influence (directly or indirectly) innovation performance. The intent was to use a reduced form supply-demand innovation equation which would have some or all of the following variables:

Measures of innovation performance (dependent variables):

- patents,
- innovations weighted by their significance,
- number of new chemical entities (NCE),
- NCE sales, or
- NCE sales intensity.

Determinants of innovation performance (independent variables):

- supply of labor,
- research intensity,
- innovation intensity,
- degree of market concentration,
- underlying capital stock and technological change,
- capital availability,
- market uncertainty,
- cost of innovation,
- cost of commercialization,
- attractiveness of chemicals industry,
- relative prices of inputs, and
- current profits.

Conceptually, innovation may be viewed as an output of one production process and an input to another. In the former case, innovation is produced from various combinations of inputs (such as researcher hours, laboratory facilities, etc.). This production activity is not well understood by economists, consequently a model of this process must use proxy variables to represent many of the production inputs, as well as to represent innovative output. Variables which explain innovation as a production output may be classified as "supply-side variables."

Innovation is also an input to the chemical production process; other inputs include capital, labor, and raw materials. It is expected that the demand for innovation as a production input would be a function of the total demand for output of the chemical production process and the relative prices of innovation and the other production inputs (assuming a non-zero elasticity of substitution between production inputs). Variables which explain innovation as an input to the chemical production may be classified as "demand-side variables."

Ideally, it would be desirable to estimate these two production functions separately, and use the resulting supply and demand curves to determine the market-clearing level of innovation. This is impossible both because the conceptual basis for many variables is fuzzy and because of data limitations. A second best approach is the estimation of a single equation containing both supply and demand explanatory variables.

Dependent Variables

As noted above, innovation is not a directly measurable concept, hence it was necessary to devise a workable proxy. The simplest solution, from a data collection standpoint, would be to use patent data. This approach is

conceptually deficient, however, since many firms patent a large number of variations of a single innovation in order to protect against other firms entering the market with nearly identical products. Furthermore, in some instances firms believe that maintaining new products or processes as trade secrets may afford more protection than the patent office. Consequently, while a variable based on patent data may provide a useful first approximation for the purpose of the simple model, theoretical problems with its application mean that it is preferable to use other proxies as well.

Several different measures of innovation based on the number of "new chemical entities" (NCE's) are possible. The simplest measure is the number of NCE's produced (either by a firm or an SIC group). Total sales contributed by NCE's over their first x years would provide more information. Innovative output can also be measured by new chemical entity sales intensity. This would take the form of the ratio of sales in a given year of all new chemicals introduced within the last x years to total sales in that year. Comanor used a similar measure of innovation output in his study of the pharmaceuticals industry.* NCE sales intensity is preferred to either numbers of NCE's or NCE sales as a measure of innovative output. NCE sales intensity normalizes innovative activity by size, that is, the relative degree of innovation across the major product groups can be compared.

Independent Variables--Supply-Side

The first variable (supply of labor) is fairly straight-forward; it reflects the labor input to the innovation production process. As noted above, this production process is not understood sufficiently well to

*Comanor, William S., "Research and Technical Change in the Pharmaceutical Industry," The Review of Economics and Statistics, Vol. 47, No. 2 (May, 1965), pp. 182-190.

permit the use of a function which merely specifies physical inputs and outputs. Consequently other variables have been added that describe the conditions surrounding the production process. For example, it is well known that certain segments of the chemical industry experience greater quantities of innovative activity than others. This may be due to greater technical opportunities in a particular industry segment, or it may be due to other factors which affect R+D expenditure and innovative intensity. The underlying initial stock of technical knowledge is designed to capture the differences in technical opportunities between industry segments, while research intensity and innovative intensity are designed to measure inter-segment differences in innovation and R+D which cannot be explained more directly.

Degree of market concentration and market uncertainty serve similar purposes. A connection has long been hypothesized between innovation and concentration resulting from either of two causes. On the one hand, it is argued that competition is required to provide the incentive for firms to innovate. On the other hand, some degree of monopoly may be a prerequisite to innovation both in order to provide funds for new product development and to insure that firms reap the rewards from successful innovation. Empirical evidence on this subject is sketchy, in part due to the difficulty of separating the effects of monopoly power from those of simply large scale.

The market uncertainty variable stems from the observation that a firm's ability to develop new products (even useful new products) does not imply the ability to successfully market those products. Differences in the innovation gestation period may stem from economic sources or may be simply reflective of the institutional differences between industry

segments. For example, in the pharmaceutical industry, the ability to locate the appropriate market (physicians) and the existence of established advertising media reduce market uncertainty. On the other hand, regulations such as the Food and Drug Act or TSCA can be expected to make marketing more difficult, and hence, increase uncertainty.

Cost of R+D and cost of commercialization might well have been included as either supply or demand variables since they may be viewed as representing the prices of inputs to the innovation production process or as proxies for the price of innovation as an input to the chemical production process. In either case, it is anticipated that TSCA would generally raise the costs of R+D and commercialization, requiring greater research for each unit of innovation and causing substitution away from innovation to other inputs in the chemical production process.

Independent Variables--Demand-Side

Several of the variables discussed in the previous section also influence the demand for innovation as an input to the chemical industry production function. These include costs of R+D and costs of commercialization discussed directly above as well as some variables which key off specific industry characteristics (e.g., concentration). Additional demand-side variables include those related to the demand for chemicals as reflected in supply variables, attractiveness of the chemicals industry and current profits, and variables related to the relative prices of the various production inputs, relative prices. These variables are used because the overall demand for chemicals influences the level of all inputs required while the relative prices of those inputs influence the quantity of each that will be employed in the production process.

Conclusions

Although many of the variables and relationships described in this approach are also used in the methodology finally adopted in this study, it was felt that use of a single equation reduced form equation was an oversimplified approach that could lead to many difficulties in interpretation. The three equation model described in Section 4 provides a more structured approach which isolates several important stages of the innovation process, and hence was considered to be superior to the reduced form model.

Section 4

The Innovation Model

Introduction

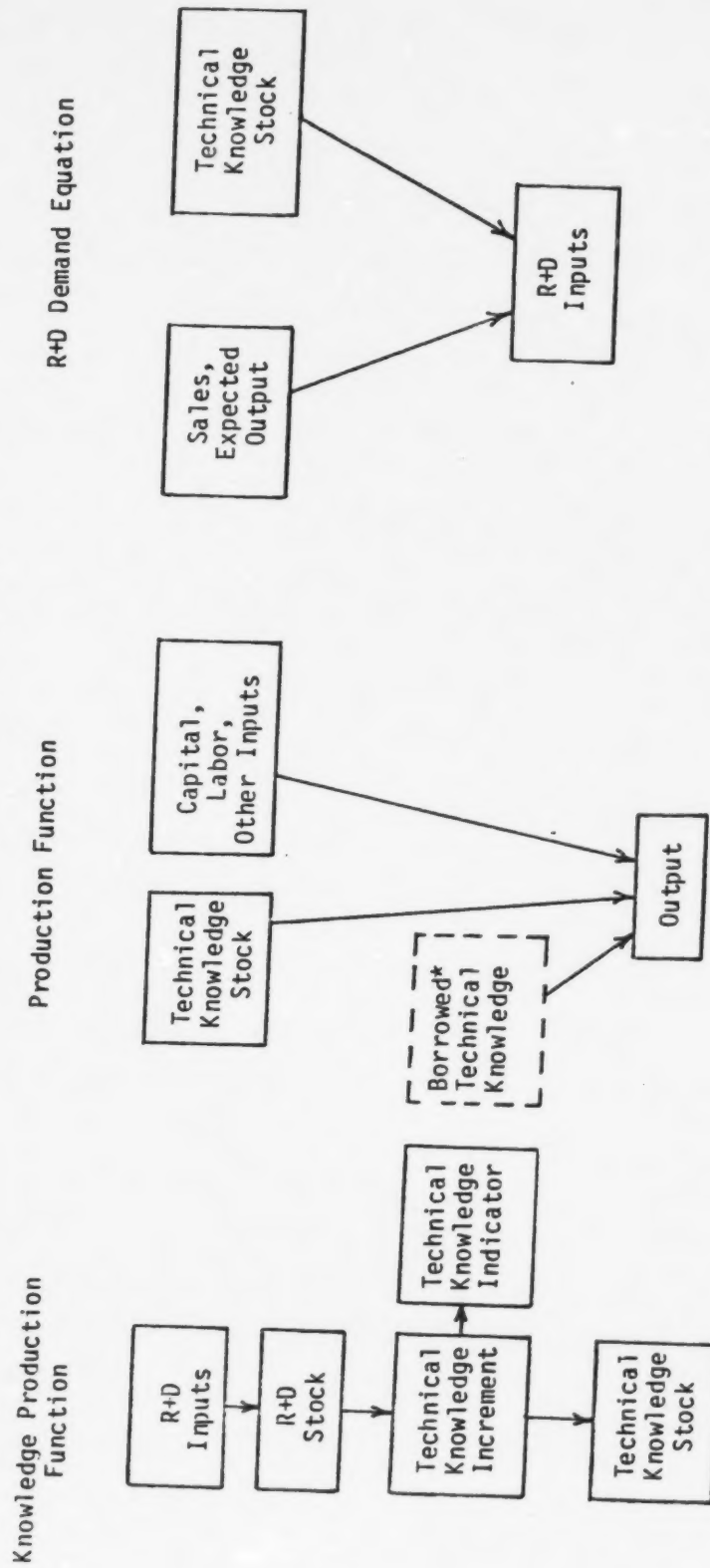
This section describes a three-equation model of innovation on which our work is focused. The model includes the following three relationships:

- 1) a technical knowledge production function with technical knowledge as a function of research and development inputs;
- 2) a production function with output as a function of conventional inputs (capital, labor, and materials) and a "stock" of knowledge; and
- 3) a derived demand equation for innovation inputs.

This approach was chosen because it presents a plausible structuring of the relationship between R+D activities, the outputs of those activities in terms of their effect on factor productivity (thereby affecting sales, profits and other indicators of business activity), the feedback of these affects on the demand for R+D, and other factors which determines the costs of R+D. The model can be estimated at the firm level using publicly available data, although the analysis would be enhanced if confidential data can be obtained. It also provides a number of ways of modeling possible TSCA impacts at various stages of the innovation process. These approaches are discussed for each of the equations in the model.

Figure 4-1 is a schematic model of the firm's research and production process which underlies the three equations. The left of Figure 4-1 shows the relation between R+D inputs and the creation of an "increment to knowledge" such as a new chemical entity (NCE) or new process. Increments to knowledge are not directly observable; however, patents, publications,

Figure 4-1
The Research and Production Process



*Not represented in our equations.

or other such indicators may be useful proxies for innovation outputs. A given increment to knowledge typically results from R+D expenditures over a number of years. This process may be modeled using the concept of an R+D "stock" which summarizes the effect of expenditures over several years. In turn, increments to knowledge by the firm over a number of years may be considered to contribute to a "stock" of technical knowledge which affects its overall productivity.

The middle of Figure 4-1 shows the firm's output as a function of capital, labor, other inputs, and the stock of technical knowledge. The knowledge stock is also unobservable, but may be measured by a proxy based on R+D expenditures or indicators of increments to technical knowledge. The knowledge stock is expected to "depreciate" in usefulness over time, faster for the individual firm than for the industry as a whole since the firm can lose its technological advantage to other firms. Similarly, the firm can borrow technical knowledge from other firms. The knowledge stock together with other factors contributes to total factor productivity. Total factor productivity is the amount of output produced by an average unit bundle of conventional physical inputs. The level of total factor productivity describes the amount of output that can be produced with given amount of conventional inputs.

Finally, the right side of Figure 4-1 gives the determinants of the firm's R+D effort. Demand for R+D is determined jointly by a number of factors, including the expected growth of future output and profits.

The Knowledge Production Function

The R+D process may be conceived of as the use of various scientific and technical inputs to develop a body of technical knowledge which the

firm uses to maintain and enhance its production possibilities.* For the chemical industry, typical additions to this body of knowledge (innovation) consist of new chemical entities (NCE's), new uses for existing chemicals, new processes, and cost savings for existing processes. (The first two kinds of innovation are subject to TSCA regulations while the last two are not.) The knowledge production function attempts to relate measures of R+D inputs to some measure of addition to knowledge. The methodology used here follows that developed by Griliches, Schankerman and Pakes, among others. Rather than focusing on individual projects, it is attempted to develop equations which described the average relationship between a firm's R+D inputs and its innovation outputs.**

Following Pakes and Griliches***, we define K as the level or stock of economically valuable technical knowledge, where $\dot{K}$ is the net accretion to K per unit of time. The model we are using assumes that K is produced by current and past research and development activities:

$$K = f(\bar{R}) + \epsilon \quad (4-1)$$

where $\bar{R}$ is the "stock" of R+D and $f(\bar{R})$ is the "technical knowledge production function." ϵ is an error term reflecting the effects of other variables neglected in the analysis. The stock of R+D is measured by a

*In practice, the line between R+D and commercialization is fuzzy, since the innovation does not begin to benefit the firm until the commercialization process is complete.

**If data are available, this analysis could also be performed at the product line level within a firm.

***This section is in large part based on "Patents and R and D at the Firm Level: A First Look" by Ariel Pakes and Zvi Griliches, National Bureau of Economic Research, Inc., Working Paper No. 651, October 1980.

combination of R+D expenditures in different years, i.e., a lag structure of R+D expenditures such as

$$\bar{R} = R_0 + (1-\delta)R_{-1} + (1-\delta)^2 R_{-2} + (1-\delta)^3 R_{-3} \quad (4-2)$$

where

R_i = R+D expenditures in year i , and

δ = an R+D depreciation or decay rate.

The use of several years reflects the fact that particular innovations result from R+D expenditures over a number of years. The notion that a firm's technical knowledge decays over time is discussed by Griliches.* For example, if only current R+D affects the production of technical knowledge, then

$$\bar{R} = R_0 \quad .$$

The stock of knowledge, K and its net accretion, $\dot{K}$, are unobservable variables; they must be measured with surrogate indicators. In our work to date we have considered several candidate indicators of $\dot{K}$ including the number of new chemical entities, new chemical sales intensity, the number of new patents, weighted patent counts, and the number of significant innovations. In the work we report here we use patent data because they are more readily obtainable than the other innovation indicators.

*Zvi Griliches, "Issues in Assessing the Contribution of Research and Development to Productivity Growth" Bell Journal of Economics, v. 10, no. 1, 1979.

There are problems in using patent data as the indicator of K . The first problem relates to the propensity of a firm to patent its inventions. That propensity (as measured, say, by the number of patents per patentable invention) may change over time as the firm changes its marketing, competitive, or R+D strategy. If the propensity to patent changes significantly, patents will be a poor measure of $\dot{K}$. Differences in the propensity to patent among firms also make patent data less reliable. However, there are econometric techniques for dealing with these problems, such as testing firm-specific constant terms. These are discussed in Section 5 on the empirical results.

The second problem in using patent data relates to differences among inventions. Some patents are for important breakthroughs in technology and others are for marginal changes in products or processes. Consequently, a patent count may hide important factors concerning $\dot{K}$.

Since $\dot{K}$ is an unobservable variable, the relationship must be estimated using an observable variable, P , which is a surrogate for $\dot{K}$. This can be expressed as:

$$P = g(\dot{K}) + \mu, \quad (4-3)$$

where μ is an error term and $g()$ the functional relationship between P and $\dot{K}$. Thus the model has the two equations:

$$\dot{K} = f(K) + \epsilon$$

$$P = g(\dot{K}) + \mu.$$

The specific functional form of both the knowledge production function and the indicator function can be hypothesized, but since $\dot{K}$ is unobservable we must estimate the function:

$$P = h(\bar{R}) + \eta \quad (4-4)$$

This function thus combines the effects of the knowledge production function and the indicator function, and the error term η contains the effects of both error terms, ϵ and η .

The functional forms used in our patent equation research are

$$P = \alpha \bar{R}^{\beta} \quad (4-5)$$

and

$$P = \alpha \bar{R}^{\beta} e^{-\lambda t} \quad (4-6)$$

where

P = the number of patents

$\bar{R}$ = the stock of R+D

t = a time index, and α , β , and λ are constants.

In the latter form, a time trend (λ) is introduced representing the possible rate of decline in opportunities or propensity to patent over time.

In all of the estimating functions, the method of determining the lag structure of the R+D stock must be chosen. Two approaches are possible. The first is to assume a particular form for the lag structure and then estimate the equations using that form. The second is to use the estimating procedure to derive a lag structure. We used the first approach due to the short time series represented by the data.

Impacts of TSCA

The formulas in equations (4-5) and (4-6) afford some straightforward ways to model TSCA impacts. The parameter " α " may be interpreted as a measure of the productivity of R+D expenditures. Therefore, an increase in R+D costs associated with a given rate of innovation is equivalent to a reduction in the productivity of R+D expenditures (including TSCA costs) in terms of innovation. This may be represented as an adjustment factor w , $0 < w < 1$, such that, post-TSCA, the innovation relationship is:

$$\dot{K} = w \alpha R^{\beta} \quad (4-7)$$

The w term can also be interpreted as a probability of success. The lower the probability of success, the higher is the R+D cost per successful innovation. The value of w could be obtained from other studies, or by estimation from pre- and post-TSCA data.

Note that since the w term represents a percentage cost increase or probability decrease, the units of the dependent variable (increments to knowledge) need not be the number of new chemical entities; they can be anything correlated with NCE's. All that is needed is an estimate of the percentage change in the cost of generating NCE's from some other source. As long as the observed dependent variable is reasonably well correlated with NCE's, the impact should be comparable. This observation is important, because it is very difficult to obtain data on the absolute number of NCE's, except from the PMNs themselves which are only available after TSCA began. Of course, the correlation between observed variables and NCE's must be established.

The lag structure underlying the definition of the R+D stock in equation (4-5) implies a mean lag between R+D expenditures and innovative outputs. A delaying effect of PMN's may be interpreted and modeled as an increase in the mean lag. (However, PMN's may play a more important role in the gestation lag between the increment to knowledge and profits. See the discussion of the R+D demand equation below.)

Production Function

Our second equation is a production function for a firm's normal output which includes a measure of a firm's stock of knowledge as a separate input to the production process (in addition to capital, labor, and material inputs). This function takes the general form

$$Q = F(C, L, M, K, t) \quad (4-8)$$

where

Q = gross output (sales, suitably deflated),
 C = measure of capital stock,
 L = employment,
 M = materials purchased,
 K = knowledge stock, and
 t = time trend.

The production function shows how production varies with different mixes of inputs. Treating the knowledge stock like another factor of production is equivalent to assuming that a firm can produce the same amount of output with fewer normal inputs if it has a greater stock of technical knowledge to rely on.

This specification entails a number of simplifying assumptions. It does not take into account the changing mix of products which results from

product innovation; the specification of the effect of the knowledge stock implies that the only kind of innovation is process change. It also does not specify that product innovation affects overall sales only through the growth of new chemical sales, not the sales of established commodity chemicals. The production function only captures the private gains of the firm; any benefits passed on to customers in the form of lower prices are not detected. In more general terms, the equation describes only the production function, but future sales can be estimated only by considering the joint effects of supply and demand. Nevertheless, increased sales and profits are the basic motivations to firms for conducting R+D, so it seems reasonable to expect to be able to identify a positive relationship between the two. Also, without access to confidential data it is not possible to identify the fraction of firm sales made up by new chemical products.

A more general problem with firm-level data is that large chemical firms typically produce in a variety of major industries. Therefore, it is generally impossible to identify relationships specific to the chemical industry. This problem is discussed more fully in Section 5.

An alternative formulation of the production function uses value-added rather than gross output as the left-hand variable, and drops materials (M) from the right-hand side. The conditions under which either functional form produces equivalent results are identified in Fuss and McFadden (1978).^{*} Basically, the production must have weak separability of the inputs. Both forms are estimated in Section 5.

^{*} Fuss, M. and D. McFadden, 1978. Production Economics: A Dual Approach to Theory and Applications, North Holland-Elsevier.

The specific functional form that we use is the Cobb-Douglas, i.e.,

$$Q = aL^{\alpha}C^{\beta}K^{\gamma}M^{\delta}e^{\lambda t} \quad (4-9)$$

Although this specification imposes some strong assumptions about the rates of substitution between factors, this issue is not a major concern in this analysis. We are mainly interested in the effects of K on Q and on any changes in this relationship which might be attributed to TSCA. Material purchased is not used in the equation due to lack of data and the stock of R+D is used as a proxy for the stock of knowledge. The omission of materials from the production function can introduce errors in the estimation of the parameters. However, our work includes experiments that suggest that the omission of M does not seriously affect the equation.

Impacts of TSCA

The production function includes a measure of the stock of knowledge together with conventional inputs, capital and labor, as determinants of output. This specification allows the effects of changes of the R+D stock due to TSCA on the rate of productivity growth in the industry to be measured. A more complete model might then show the effect of a reduced rate of innovation on the growth rate of sales and profits. For example, the rate of penetration of chemicals into certain end-uses may be shown to depend on the ratio of chemical prices to prices of inputs made from other materials. If innovations can be translated into equivalent cost reductions, then the effect of a reduction in the rate of innovation on the rate of penetration could be shown. Estimates of such an effect on the growth rate could then be plugged into the R+D demand equation to capture secondary effects via the R+D demand equation (described in the next subsection). However, this would require an explicit modeling of

demand/supply interaction which is beyond the scope of this study.

Alternatively, this effect on growth could be estimated based on other sources.

R+D Demand Equation

The R+D demand equation is the final element of the innovation model and closes the feedback loop by specifying that R+D expenditures (inputs to the knowledge production function) depend on firm's expectations of future sales growth which results from increases in the stock of knowledge via the two other equations.

Our formulation of the R+D equation is based on the assumption that the firm will invest in R+D up to the point at which the added present value of the benefits equals the added cost. Innovation is assumed to take the form of reductions in unit production costs, or the equivalent effect of new products. Benefits of these cost savings are assumed proportionate to total sales. The equation explicitly incorporates the specification of the knowledge production function. The derivation of the R+D equation is given in Appendix E. Two forms of the R+D demand equations are derived. In the first, R+D expenditures are given as a function of last year's R+D expenditures, current sales, and the anticipated growth rate of production. In the second, the intensity of R+D--R+D as a percentage of sales--is a function of last year's R+D intensity and the expected growth rate of production.

The specifications of the R+D demand equation include parameters for the firm's discount rate, the rate of depreciation of technical knowledge, and the gestation lag between innovation and benefits from cost reductions. The coefficients obtained from the empirical estimation can be tested to

determine whether they imply reasonable values for these parameters. As described below, these parameters provide a means for modeling the impacts of TSCA.

As usual, the model has a number of simplifying assumptions. Firms are assumed to forecast correctly (except for a random error term) the growth rate of the future sales and the benefits accruing to them in all future periods resulting from current R+D efforts. Cost savings are assumed to be a constant fraction of price in each period.

Impacts of TSCA

The R+D demand equation incorporates the knowledge production function described in the previous section together with estimates of the gestation lag between innovation and the first returns from it, the rate of the decay of useful knowledge, the expected growth rate of sales and the discount rate. The knowledge production function reflects any changes in R+D productivity due to TSCA. The gestation lag can be adjusted to account for TSCA impacts which delay the introduction of new chemical entities to the market. The rate of depreciation of knowledge might also be adjusted downward to reflect a lessening of competitive pressure due to reduced R+D.

The final form of the R+D demand equation in Appendix E is:

$$\ln R_0^* = a'' + bg + \ln P_0Q_0 \quad (4-10)$$

where:

R_0^* = desired R+D expenditures in year 0

g = expected growth rate of sales

P_0Q_0 = sales in year 0

and

$$a'' = \ln \alpha k - (r+\delta) \theta - \ln (r+\delta) - \ln (1 - \phi)$$

$$b = \frac{1}{r - \delta} + \theta$$

where:*

- ϕ = ratio of unit gross profit to price of output
- k = growth rate of knowledge stock
- r = discount rate
- δ = annual depreciation rate of benefits of R+D to firm
- θ = gestation lag (in years)
- α = elasticity of K with respect to R+D stock (from knowledge production function)

TSCA-related costs affect desired R+D both through the constant term and the coefficient of the growth of sales term. There is a secondary effect if TSCA affects the expected rate of growth of sales g as well. Estimates of the effect of TSCA on R+D can be made by making assumptions about the TSCA-related "knobs" α , θ and δ .

*The rates ϕ , k , r and δ are expressed as fractions, not percents.

Section 5

Data and Results

Introduction

This section describes the data used to estimate the three-equation model of innovation outlined in Section 4, the estimation results, and the interpretation and limitations of the results. The work presented thus far must be regarded as preliminary; proposals for further work are given in Section 7. There are a number of limitations, including an over-aggregated and probably biased sample of the industry, reliance solely on patents as a measure of innovation output, and a number of estimation issues that remain to be resolved. Nevertheless, the results are encouraging in that the estimated relations have a high statistical significance and the coefficient estimates imply reasonable values for important parameters in the theoretical models.

Data Sample

There are about 1,500 firms that produce chemicals and allied products*. Annual data were assembled initially for 80 publicly owned firms covering a twenty year period of interest, 1960-1980. Data availability and involvement in the chemical industry determined the selection of firms in the sample. Only publicly-owned firms were included because financial data on them can be obtained from sources such as annual reports and 10-K reports provided by the Securities and Exchange Commission (SEC). The sample of firms was compiled from several sources, including trade literature lists of major chemical firms and firms

*SRI International 1979 Directory of Chemical Producers.

identified as belonging to the major chemical-related SIC groups (see Table 5-1) as identified in the listing of the "Disclosure" data base.* This selection procedure has biased the sample to large diversified firms, whose innovation behavior may differ significantly from that of smaller, more specialized firms. Also, the aggregate financial data used in this study includes activities by firms in a wide range of areas, cutting across many important strategic groups within the industry and including a number of areas outside the chemical industry. Therefore, differences in innovation across industrial groups are likely to be obscured. Section 7 proposes a number of remedies for these deficiencies.

Two main kinds of data are used in the analysis: firm financial data and measures of innovation, in this case, counts of patent applications. The knowledge production function relates R+D expenditures to patent applications. The firm's production function relates a stock of knowledge (using R+D expenditures as a proxy) and other inputs to the firm's output (deflated sales) or value-added. Finally, the R+D demand equation relates the expected rate of firm's sales growth to their R+D expenditures. As stated previously, these data were obtained at the firm level, except for value-added. Financial data including sales revenue, R+D expenditures, capital expenditures and employment were taken from firms' 10-K and annual reports. Value added data by four-digit SIC group were obtained from the Census of Manufacturers. Counts of patent applications are from the data base of the U.S. Patent Office, Office of Technology Assessment and Forecasting (OTAF).**

*Disclosure, Inc., 5161 River Rd., Washington, DC 20016, has an on-line data base containing financial data on publicly-owned firms acquired by the SEC.

**These are counts of chemical industry patents alone, not all patents acquired by these firms.

Data for each company and each variable were not obtainable for all the twenty years of interest. For example, R+D expenditures for the first half of the 1960 decade are not readily available for many of the firms. Also, patent application counts in the OTAF data base are for the period 1968 through 1979 but the counts for the beginning and end years of this interval may be distorted. (The patent data acquired from the U.S. Patent Office contain the number of patents applied for and the number of patents granted by year and by company. However both patent grants and applications are counted only for those actually granted in the 1969-1979 period. For example, a patent application made in 1978 but granted in 1980, or a patent application made in 1968 and granted in 1970 are not included in the OTAF file.) Other data such as those on capital expenditures and employment were not available for some firms.

For the reasons outlined above, only 48 of the 80 firms were included in the data base constructed for the regression analyses. The firms are identified in Table 5-1 which also shows the manufacturing activities of each firm with respect to the SIC industry groups included in the project scope. Many of the 48 firms also are active in other industry sectors (defined in Table 5-2) and this is noted at the bottom of Table 5-1 for each firm. Based on 1980 data, the firms range in size, based on sales revenue from \$54.4 million to \$13.6 billion, based on employment, they range in size from 300 to 135,000.

Four indices were used in constructing the variables of the equations: the GNP deflator, the Department of Commerce producers price index for chemicals and allied products, the Chemical Engineering plant cost index, and an R+D cost index from the "PMA Newsletter." In the

Table 5-1
Manufacturing Activities of Firms in Data Sample

SIC Code	Description	Industrial Sectors	Name of Firm	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100	2101	2102	2103	2104	2105	2106	2107	2108	2109	2110	2111	2112	2113	2114	2115	2116	2117	2118	2119	2120	2121	2122	2123	2124	2125	2126	2127	2128	2129	2130	2131	2132	2133	2134	2135	2136	2137	2138	2139	2140	2141	2142	2143	2144	2145	2146	2147	2148	2149	2150	2151	2152	2153	2154	2155	2156	2157	2158	2159	2160	2161	2162	2163	2164	2165	2166	2167	2168	2169	2170	2171	2172	2173	2174	2175	2176	2177	2178	2179	2180	2181	2182	2183	2184	2185	2186	2187	2188	2189	2190	2191	2192	2193	2194	2195	2196	2197	2198	2199	2200	2201	2202	2203	2204	2205	2206	2207	2208	2209	2210	2211	2212	2213	2214	2215	2216	2217	2218	2219	2220	2221	2222	2223	2224	2225	2226	2227	2228	2229	2230	2231	2232	2233	2234	2235	2236	2237	2238	2239	2240	2241	2242	2243	2244	2245	2246	2247	2248	2249	2250	2251	2252	2253	2254	2255	2256	2257	2258	2259	2260	2261	2262	2263	2264	2265	2266	2267	2268	2269	2270	2271	2272	2273	2274	2275	2276	2277	2278	2279	2280	2281	2282	2283	2284	2285	2286	2287	2288	2289	2290	2291	2292	2293	2294	2295	2296	2297	2298	2299	2300	2301	2302	2303	2304	2305	2306	2307	2308	2309	2310	2311	2312	2313	2314	2315	2316	2317	2318	2319	2320	2321	2322	2323	2324	2325	2326	2327	2328	2329	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350	2351	2352	2353	2354	2355	2356	2357	2358	2359	2360	2361	2362	2363	2364	2365	2366	2367	2368	2369	2370	2371	2372	2373	2374	2375	2376	2377	2378	2379	2380	2381	2382	2383	2384	2385	2386	2387	2388	2389	2390	2391	2392	2393	2394	2395	2396	2397	2398	2399	2400	2401	2402	2403	2404	2405	2406	2407	2408	2409	2410	2411	2412	2413	2414	2415	2416	2417	2418	2419	2420	2421	2422	2423	2424	2425	2426	2427	2428	2429	2430	2431	2432	2433	2434	2435	2436	2437	2438	2439	2440	2441	2442	2443	2444	2445	2446	2447	2448	2449	2450	2451	2452	2453	2454	2455	2456	2457	2458	2459	2460	2461	2462	2463	2464	2465	2466	2467	2468	2469	2470	2471	2472	2473	2474	2475	2476	2477	2478	2479	2480	2481	2482	2483	2484	2485	2486	2487	2488	2489	2490	2491	2492	2493	2494	2495	2496	2497	2498	2499	2500	2501	2502	2503	2504	2505	2506	2507	2508	2509	2510	2511	2512	2513	2514	2515	2516	2517	2518	2519	2520	2521	2522	2523	2524	2525	2526	2527	2528	2529	2530	2531	2532	2533	2534	2535	2536	2537	2538	2539	2540	2541	2542	2543	2544	2545	2546	2547	2548	2549	2550	2551	2552	2553	2554	2555	2556	2557	2558	2559	2560	2561	2562	2563	2564	2565	2566	2567	2568	2569	2570	2571	2572	2573	2574	2575	2576	2577	2578	2579	2580	2581	2582	2583	2584	2585	2586	2587	2588	2589	2590	2591	2592	2593	2594	2595	2596	2597	2598	2599	2600	2601	2602	2603	2604	2605	2606	2607	2608	2609	2610	2611	2612	2613	2614	2615	2616	2617	2618	2619	2620	2621	2622	2623	2624	2625	2626	2627	2628	2629	2630	2631	2632	2633	2634	2635	2636	2637	2638	2639	2640	2641	2642	2643	2644	2645	2646	2647	2648	2649	2650	2651	2652	2653	2654	2655	2656	2657	2658	2659	2660	2661	2662	2663	2664	2665	2666	2667	2668	2669	2670	2671	2672	2673	2674	2675	2676	2677	2678	2679	2680	2681	2682	2683	2684	2685	2686	2687	2688	2689	2690	2691	2692	2693	2694	2695	2696	2697	2698	2699	2700	2701	2702	2703	2704	2705	2706	2707	2708	2709	2710	2711	2712	2713	2714	2715	2716	2717	2718	2719	2720	2721	2722	2723	2724	2725	2726	2727	2728	2729	2730	2731	2732	2733	2734	2735	2736	2737	2738	2739	2740	2741	2742	2743	2744	2745	2746	2747	2748	2749	2750	2751	2752	2753	2754	2755	2756	2757	2758	2759	2760	2761	2762	2763	2764	2765	2766	2767	2768	2769	2770	2771	2772	2773	2774	2775	2776	2777	2778	2779	2780	2781	2782	2783	2784	2785	2786	2787	2788	2789	2790	2791	2792	2793	2794	2795	2796	2797	2798	2799	2800	2801	2802	2803	2804	2805	2806	2807	2808	2809	2810	2811	2812	2813	2814	2815	2816	2817	2818	2819	2820	2821	2822	2823	2824	2825	2826	2827	2828	2829	2830	2831	2832	2833	2834	2835	2836	2837	2838	2839	2840	2841	2842	2843	2844	2845	2846	2847	2848	2849	2850	2851	2852	2853	2854	2855	2856	2857	2858	2859	2860	2861	2862	2863	2864	2865	2866	2867	2868	2869	2870	2871	2872	2873	2874	2875	2876	2877	2878	2879	2880	2881	2882	2883	2884	2885	2886	2887	2888	2889	2890	2891	2892	2893	2894	2895	2896	2897	2898	2899	2900	2901	2902	2903	2904	2905	2906	2907	2908	2909	2910	2911	2912	2913	2914	2915	2916	2917	2918	2919	2920	2921	2922	2923	2924	2925	2926	2927	2928	2929	2930	2931	2932	2933	2934	2935	2936	2937	2938	2939	2940	2941	2942	2943	2944	2945	2946	2947	2948	2949	2950	2951	2952	2953	2954	2955	2956	2957	2958	2959	2960	2961	2962	2963	2964	2965	2966	2967	2968	2969	2970	2971	2972	2973	2974	2975	2976	2977	2978	2979	2980	2981	2982	2983	2984	2985	2986	2987	2988	2989	2990	2991	2992	2993	2994	2995	2996	2997	2998	2999	3000	3001	3002	3003	3004	3005	3006	3007	3008	3009	3010	3011	3012	3013	3014	3015	3016	3017	3018	3019	3020	3021	3022	3023	3024	3025	3026	3027	3028	3029	3030	3031	3032	3033	3034	3035	3036	3037	3038	3039	3040	3041	3042	3043	3044	3045	3046	3047	3048	3049	3050	3051	3052	3053	3054	3055	3056	3057	3058	3059	3060	3061	3062	3063	3064	3065	3066	3067	3068	3069	3070	3071	3072	3073	3074	3075	3076	3077	3078	3079	3080	3081	3082	3083	3084	3085	3086	3087	3088	3089	3090	3091	3092	3093	3094	3095	3096	3097	3098	3099	3100	3101	3102	3103	3104	3105	3106	3107	3108	3109	3110	3111	3112	3113	3114	3115	3116	3117	3118	3119	3120	3121	3122	3123	3124	3125	3126	3127	3128	3129	3130	3131	3132	3133	3134	3135	3136	3137	3138	3139	3140	3141	3142	3143	3144	3145	3146	3147	3148	3149	3150	3151	3152	3153	3154	3155	3156	3157	3158	3159	3160	3161	3162	3163	3164	3165	3166	3167	3168	3169	3170	3171	3172	3173	3174	3175	3176	3177	3178	3179	3180	3181	3182	3183	3184	3185	3186	3187	3188	3189	3190	3191	3192	3193	3194	3195	3196	3197	3198	3199	3200	3201	3202	3203	3204	3205	3206	3207	3208	3209	3210	3211	3212	3213	3214	3215	3216	3217	3218	3219	3220	3221	3222	3223	3224	3225	3226	3227	3228	3229	3230	3231	3232	3233	3234	3235	3236	3237	3238	3239	3240	3241	3242	3243	3244	3245	3246	3247	3248	3249	3250	3251	3252	3253	3254	3255	3256	3257	3258	3259	3260	3261	3262	3263	3264	3265	3266	3267	3268	3269	3270	3271	3272	3273	3274	3275	3276	3277	3278	3279	3280	3281	3282	3283	3284	3285	3286	3287	3288	3289	3290	3291	3292	3293	3294	3295	3296	3297	3298	3299	3300	3301	3302	3303	3304	3305	3306	3307	3308	3309	3310	3311	3312	3313	3314	3315	3316	3317	3318	3319	3320	3321	3322	3323	3324	3325	3326	3327	3328	3329	3330	3331	3332	3333	3334	3335	3336	3337	333
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Table 5-1
Manufacturing Activities of Firms in Data Sample
(continued)

SIC Code	Description	Industrial Sectors	Hooker Chemicals & Plastics Inc.	Infra Chemical Corp.	Lea - Royal Inc.	Locite Corp.	Lubrizol Corp.	Monsanto Co.	Norton Norton Products Inc.	NL Industries Inc.	Oakite Products Inc.	Olin Corp.	Pennwalt Corp.	Pratt & Lambert, Inc.	Products Research Corp.	Staufner Chemical Co.	Staufner Corp.	Union Carbide Corp.	Valpar Corp.	West Chemical Products, Inc.	Weyerhaeuser Inc.				
2801	Industrial chemicals		X																						
2802	Alkalies and coloring																								
2803	Inorganic gases																								
2804	Inorganic pigments																								
2805	Inorganic organics not elsewhere classified (NEC)																								
2806	Plastics, synthetic resin, rubber, other fibers except glass																								
2807	Plastic materials, synthetic resins, non-vulcanized elastomers																								
2808	Synthetic rubber																								
2809	Cellulosic man-made fibers																								
2810	Synthetic organic fibers, except cellulosic																								
2811	Soaps, detergents, cleaning prep., cosmetics, toilet prep.																								
2812	Soap and other intermediates, except specialty cleaners																								
2813	Specialty cleaning, polishing and sanitation preparations																								
2814	Surface active agents, finishing agents, surfactants																								
2815	Perfumes, cosmetics and other toilet preparations																								
2816	Paints, varnishes, enamels, inks, dyes, etc.																								
2817	Industrial inorganic chemicals																								
2818	Gas and liquid fuels																								
2819	Cyclic co. p. intermediates, dyes and pigments																								
2820	Industrial organic chemicals																								
2821	Agricultural chemicals																								
2822	Nitrogenous fertilizers																								
2823	Phosphoric fertilizers																								
2824	Fertilizers - mixing only																								
2825	Miscellaneous chemical products																								
2826	Adhesives and sealants																								
2827	Explosives																								
2828	Printing ink																								
2829	Carbon black																								
2830	Chemical and chemical products NEC																								
2831	Petroleum refining																								
Sales, 1969 (\$ in millions)			1790	440	199	102	65	67	617	2110	68	1053	1100	90	48	1725	1065	150	513	9904	137	56	2044		
Employment, 1980 (thousands)			10.7	10.1	3.5	0.3	2.8	4.1	61.5	11.2	4.4	72.4	0.9	21.0	12.5	1.3	0.6	13.4	13.3	0.8	6.1	116.2	1.3	1.9	14.0
Other industrial sectors, not in project scope, in which firms are active (SIC code).			28.9	14.5	1.0	1.0	35.0	20.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	

Notes: Notes: Data for 1980 are not available, entries are: 1/ 1979, 2/ 1977 data.

Table 5-2
Industry Sectors Not in Project Scope
in Which Firms are Active

(Note: n.e.c.≡ not elsewhere classified)

SIC Code	Description
1311	Extraction of crude petroleum and natural gas
1389	Oil and gas field services, n.e.c.
1474	Mining and quarrying; potash, soda, and borate minerals
1475	Mining and quarrying; phosphate rock
1476	Mining and quarrying; rock salt
2035	Pickled fruits and vegetables; vegetable sauces and seasonings; and salad dressings
2087	Beverages; flavoring extracts and flavoring sirups, n.e.c.
2099	Miscellaneous food preparations and kindred products; food preparations, n.e.c.
2211	Broad woven fabric mills; cotton
2282	Yarn texturizing, throwing, twisting and winding mills. Cotton, man-made fibers and silk
2394	Canvas products and related products, e.g., awnings, canopies, sails, tents
2511	Wood household furniture, except upholstered
2621	Paper mills except those producing Building paper
2641	Paper coating and glazing
2831	Biological drug products
2833	Medicinal chemicals and botanical products
2834	Pharmaceutical preparations
2879	Pesticides and agricultural chemicals, n.e.c.

(continued on next page)

Table 5-2
Industry Sectors Not in Project Scope
in Which Firms are Active

SIC Code	Description
2992	Miscellaneous products of petroleum and coal: lubricating oils and greases
3079	Rubber and miscellaneous plastic products: miscellaneous plastic products
3143	Leather and leather products: men's footwear, except athletic
3221	Glass containers
3241	Cement, hydraulic
3313	Electrometallurgical products
3331	Primary smelting and refining of copper
3369	Nonferrous foundries (castings), n.e.c.
3421	Fabricated metal products; cutlery
3429	Fabricated metal products; hardware, n.e.c.
3484	Fabricated metal products; small arms
3497	Fabricated metal products; metal foil and leaf
3499	Fabricated metal products; n.e.c.
3533	Oil field machinery and equipment
3549	Metalworking machinery n.e.c.
3552	Textile machinery
3555	Printing trades machinery and products
3559	Special industry machinery, n.e.c.
3562	Ball and roller bearings
3564	Blowers and exhaust and ventilation fans

(continued on next page)

Table 5-2
Industry Sectors Not in Project Scope
in Which Firms are Active

SIC Code	Description
3569	General industrial machinery and equipment, n.e.c.
3623	Welding apparatus, electric
3641	Electric lamps
3692	Primary batteries, dry and wet
3714	Motor vehicle parts and accessories
3811	Engineering, laboratory, scientific and research instruments and equipment
3842	Orthopedic, prosthetic and surgical appliances and supplies
3843	Dental equipment and supplies
3955	Carbon paper and inked ribbons
3961	Costume jewelry, novelties, buttons and miscellaneous notions
4924	Natural gas distribution
5122	Wholesale trade in cotton
5198	Wholesale trade in paints, varnishes and supplies
5231	Paint, glass and wallpaper stores
5944	Jewelry stores
6552	Real estate developers
7349	Business services; cleaning and maintenance to buildings, n.e.c.
8911	Miscellaneous services; engineering, architectural and surveying

regression described below, all dollar values are deflated using the price indices cited above. Sales data are deflated using the GNP deflator, capital expenditures are deflated by the plant cost index, and R+D expenditures are inflated by the R+D cost index. A production index for the firm is defined as the ratio of sales to the index of chemicals and allied products producer prices for each year.

Patent Equation

The patent equation is a production relation with patents produced by R+D expenditures. The form of the equation used in most of our estimates is

$$P = a\bar{R}^{\alpha} \quad (5-1)$$

- variable $\bar{R}$, the stock of R+D, is defined as a weighted sum of past R+D expenditures. Recall that a particular innovation is likely to depend on R+D expenditures made over a period of years. We used three basic weighting structures to arrive at alternative definitions of $\bar{R}$ for the patent equation. The first basic weighting structure is based on the annual depreciation of R+D expenditures:

$$\bar{R}_0 = R_{-1} + (1-\delta)R_{-2} + (1-\delta)^2R_{-3} + \dots \quad (5-2)$$

where

δ = the depreciation rate, and

R_{-t} = R+D expenditures t years ago (millions of constant dollars).

Thus, if $\delta = .15$, then the contribution of R+D expenditures to the stock of R+D is assumed to decline 15 percent each year. The second weighting structure is the simple sum of the past several (three or four) years' R+D expenditures:

$$\bar{R} = R_{-1} + R_{-2} + R_{-3} \quad (5-3)$$

The third weighting structure is the inverted V which assigns lowest weights to those R+D expenditures that have just occurred and those that occurred a relatively long time ago. The inverted-V structure we use is as follows:

$$\bar{R} = .2R_{-1} + .4R_{-2} + .6R_{-3} + .4R_{-4} + .2R_{-5} \quad (5-4)$$

Each of the above definitions of the lag structure was tested with an initial lag of 0, 1, or 2 years. This implies different assumptions about the "gestation lag" between R+D expenditures and innovation.*

The patent equation was fitted with the pooled time series data on 48 firms described above. For most of the regressions, individual intercept terms are used for each firm, i.e., the value of the constant, a , is allowed to differ among firms. The coefficient α is constrained to be the same for all firms. This is equivalent to stating that the average productivity in terms of innovations of R+D expenditures and/or the average propensity to patent varies across firms, but the elasticity of the knowledge production function across firms is constant, i.e., an equal percent change in R+D expenditures leads to an equal percent change in patent applications.

*The gestation lag between the innovation and actual sales may be more important. See the discussion of the R+D demand equation below.

F-tests were performed to determine the significance of restricting the intercept to a single value for all firms and of allowing different values of α for different firms. Tests were also made of a linear form of the patent equation (with α set equal to one) and of a patent equation with a time trend added. These tests revealed that the restriction of α to a constant value for all firms is significant, while the restriction on α is not significant. The first result implies that we fail to reject the hypothesis that all firms have the same elasticity of patents with respect to R+D stock is accepted, i.e., equal percent changes in the R+D stock yield equal percent changes in patenting activity. The second result implies that the hypothesis that all firms have the same average R+D productivity for a given level of R+D expenditures is rejected. The fits of the regressions are good using each of the basic definitions of the stock of R+D and the difference in R^2 is not great. When intercept dummies are included, all equations have an R^2 of .99; when intercept dummies are omitted, the R^2 for all equations ranges from .78 to .80. A lag of 0 years is superior to longer lags in all cases.

The results for three of the regressions are given in Table 5-3. The regressions are in logarithm form:

$$\ln P = \ln a + \alpha \ln \bar{R} + \epsilon \quad , \quad (5-5)$$

where the constant a is the intercept variable for the firm, α the elasticity of response to R+D, and the ϵ the error term. Each firm has a separate dummy intercept variable in the regressions. The results are shown for the R+D stock defined as a 1) depreciated sum of R+D expenditures at 15 percent per year, 2) a simple three year sum, and 3) a

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Table 5-3
Patent Equation Regression Results

$$\ln P = \ln a_i + \alpha \ln \bar{R} + \epsilon$$

P = Number of patent applications

$\bar{R}$ = R+D stock (millions of dollars, deflated)

i = Index for i th firm

- 1) R+D stock as depreciated sum at 15 percent/year.

$$\alpha = 0.480 \text{ (0.176)}$$

$$-0.75 \leq \ln a_i \leq 2.61$$

$$R^2 = 0.99$$

$$F \text{ ratio} = 615 \quad d.f. = 273$$

- 2) R+D stock as simple three-year sum

$$\alpha = 0.368 \text{ (0.132)}$$

$$-0.19 \leq \ln a_i \leq 3.62$$

$$R^2 = 0.99$$

$$F \text{ ratio} = 616 \quad d.f. = 273$$

- 3) R+D stock as inverted-V weighted sum with weights .2, .4, .6, .4, .2.

$$\alpha = 0.394 \text{ (0.157)}$$

$$-0.04 \leq \ln a_i \leq 3.67$$

$$R^2 = 0.99$$

$$F \text{ ratio} = 612 \quad d.f. = 273$$

Notes: Standard errors are shown in parentheses.
 The range of intercept coefficients for firms is shown.
 Degrees of freedom are indicated by "d.f."

weighted sum using the inverted-V structure with weights .2, .4, .6, .4, and .2. All regressions use a 0-year lag. The equations are estimated using ordinary least squares (OLS) techniques.

Each table shows the coefficient estimate and standard deviation for the elasticity term α , the range of values of the firm-specific constant terms $\ln a$, the R-squared, the F ratio, and the number of degrees of freedom. The results for all three equations are broadly comparable. All have very high R-squareds. The value of the elasticity α ranges from .368 to .480 and is significant in all forms, although not to an extent which would explain the high R^2 's. This suggests that inter-firm variation, as captured by the firm-specific constant terms, provides much of the explanatory power behind the high R-squared values, rather than intra-firm variation. As noted above, the R^2 ranges from .78 to .80 when the firm-specific dummies are dropped from the equation.

For comparison, in a study using a very similar model, Pakes and Griliches* obtained an equivalent value of α of .61, with a standard error of .08. Their results also showed that between firm variation rather than intra-firm variation explains most of the variance of patenting activity. The ability to explain year to year deviations of patenting from a firm's average propensity is still weak. This also suggests a reason why using different lag structures does not affect the explanatory power of the equation much.

An elasticity α less than one implies that firm's experience declining marginal returns to R+D expenditures. It would be interesting to test

*"Patents and R and D at the Firm Level," op. cit.

whether this is offset by a positive correlation between a firm's constant term (proportional to average R+D productivity) and its size.

The marginal product in terms of patents per dollar of R+D stock is

$$\frac{d P}{d \bar{R}} = \alpha \frac{P_a}{\bar{R}_a} = 0.16 \text{ patents per million dollars}$$

where the subscript *a* denotes the average values. This implies that every additional million dollars of R+D stock results in the production of 0.16 patents. If TSCA regulations alter the ability or propensity of firms to patent, then this relation will change. For example, if the effectiveness of every R+D dollar falls to the equivalent of 90 cents, then we would expect the marginal product to fall to 0.14 patents per million dollars.

The Production Function

The form of the production function used for the regressions is the log-log Cobb-Douglas function:

$$\ln Q = \ln a + \alpha \ln L + \beta \ln C + \gamma \ln \bar{R} + \lambda t + \epsilon . \quad (5-6)$$

where:

- Q = Sales (millions of dollars, deflated)
- L = Number of employees (thousands)
- C = Capital stock (millions of dollars, deflated)
- $\bar{R}$ = R+D stock (millions of dollars, deflated)
- t = time trend

The equations are estimated using ordinary least squares. The capital stock, *C*, is defined as the depreciated sum of capital expenditures. As noted before, capital expenditures are deflated to constant dollar terms

using the Chemical Engineering plant cost index. Depreciation rates of 5, 10, and 15 percent per year were tried in the equation. The stock of R+D, $\bar{R}$, is used as a proxy for the unobservable knowledge stock, K, which was used in the specification of the production function in Section 4. A number of different definitions of the R+D stock were tried. The same three basic definitions of the lag structure of the R+D stock as described for the patent equation are used for the production function. The depreciation rates used are 10, 15, 20, and 25 percent per year and the length of lags is two and three years. These depreciation lags are greater than those used for the patent equation due to the difference between the two equations; the lag between R+D expenditures and production is greater than the lag between R+D expenditures and patent generation. A range of depreciation rates is used, reflecting uncertainty about the R+D-productivity relationship.

Employment (L) is taken directly from firm's annual reports, while t is a time-trend reflecting unexplained secular technical change.

The results for the different capital stock definitions do not differ radically. Overall, the use of the 10 percent depreciation rate for the definition of the capital stock gives good results and is the one that is used in the results presented here. The results are also quite robust with respect to the different definitions of the R+D stock. The results for two of the best regressions are given in Table 5-4.

Both regressions are estimated with separate constant terms for each firm but with identical elasticities of output with respect to each input (α, β, γ). The results of the two equations are very similar, both for the

range of constant terms and the elasticity coefficients. The R-squares are high, and all the elasticity coefficients are significant and have reasonable magnitudes. The values for the elasticity of output with respect to the R+D stock (γ) are high relative (about twice as large) to those obtained in an unpublished study by Griliches and Mairesse using a similar model. As in the case of the patent equation, it would appear that inter-firm rather than intra-firm variation contributes the bulk of the explanatory process of the equation. This should be tested further using deviations from means to capture the pure intra-firm effect. (See Section 7 for further detail.)

Tests were performed in which the intercept is restricted to a single value for all firms and which different values of the elasticity coefficients are allowed for different firms. The results indicate that average inter-firm differences are important, as reflected in the constant term, but differences in the elasticities are not, or at least are not detectable given this data. Tests were also performed restricting the production function to constant returns to scale in capital and labor ($\alpha + \beta = 1$) and constant returns to scale in capital, labor, and the R+D stock ($\alpha + \beta + \gamma = 1$). In general, the hypotheses implied by these joint restrictions were rejected. The production function was also fit using different R+D elasticity coefficients for different groups of firms. The firms were grouped in accordance with their primary SIC group. These results were not significant either.

The production function estimated equation provides an estimate of the average gross returns to the R+D stock, i.e., the marginal product of the stock. Given average values of sales and the R+D stock and the specification of the production function in equation (1) in Table 5-4, the marginal product is:

Table 5-4
Production Function Regression Results

$$\ln Q = \ln a_i + \alpha \ln L + \beta \ln C + \gamma \ln \bar{R} + \lambda t + \epsilon$$

Q = Sales (millions of dollars, deflated)

i = Index denoting ith firm

L = Number of employees (thousands)

C = Capital stock (millions of dollars, deflated)

R = R+D stock (millions of dollars, deflated)

t = time trend

- 1) R+D stock as inverted-V weighted sum with weights .2, .4, .6, .4, .2 and 3 year lag.

$$\alpha = 0.613 (0.044)$$

$$\beta = 0.154 (0.037)$$

$$\gamma = 0.166 (0.035)$$

$$\lambda = 0.017 (0.003)$$

$$1.52 \leq \ln a_i \leq 3.67$$

$$R^2 = 0.99$$

$$F \text{ ratio} = 17,797 \quad d.f. = 432$$

- 2) R+D stock as depreciated sum at 20 percent per year and 3 year lag.

$$\alpha = 0.621 (0.044)$$

$$\beta = 0.152 (0.037)$$

$$\gamma = 0.138 (0.041)$$

$$\lambda = 0.016 (0.003)$$

$$1.51 \leq \ln a_i \leq 3.62$$

$$R^2 = 0.99$$

$$F \text{ ratio} = 17,349 \quad d.f. = 432$$

Notes: Standard errors are shown in parentheses.
The range of intercept coefficients for firms is shown.
Degrees of freedom are indicated by "d.f."
Capital stock is defined as depreciated sum at 10 percent per year.

$$\frac{dQ}{d\bar{R}} = \gamma \frac{Q_a}{\bar{R}_a} = 1.75$$

If we compute the time stream of the increased sales that are associated with the expenditure of one R+D dollar, we can find the gross rate of return of R+D expenditures.

Given the inverted V-structure of the R+D stock, we can determine the contribution of a dollar increase in R+D expenditures in year 0 to sales in each of the following eight years:

<u>Year</u>	<u>Change in Sales</u>
1	0
2	0
3	0
4	.2 x 1.75 = .35
5	.4 x 1.75 = .70
6	.6 x 1.75 = 1.05
7	.4 x 1.75 = .70
8	.2 x 1.75 = .35

The gross rate of return is simply the rate of return which makes the present value of the above change in sales equal to 1 in year 0, in this case, 22 percent. It is not the net return because it includes an implied depreciation rate. Note that this is a measure of profitability because, by the definition of marginal product, all other inputs are held constant in this exercise.

Similarly we can compute the marginal value associated with a change in the lag between R+D and the realization of increased production. An increase in the lag will delay the time stream of sales which in turn can be shown to lower the rate of return.

Value Added Production Function

The production function formulation discussed above gives the quantity of output of the firm as a function of inputs of capital, labor, and the R&D stock. Because data on materials purchased are not available for individual firms, we used the form of the production function presented above. The omission of materials from the production function can result in biased and incorrect estimates of the parameters of the regression. Consequently, we performed some experiments with additional data to test a value-added production function.

Value added is equal to sales minus the cost of materials purchased:

$$V = S - M \quad (5-6)$$

where V is value added, S is sales, and M is materials purchased. In the alternative formulation of the production function, value added is used as the dependent variable:

$$V = aL^{\alpha} C^{\beta} R^{\gamma} e^{\lambda t} \quad (5-7)$$

Although we do not have firm-level data on value added, we can approximate value added by using SIC-level data from the Census of Manufactures. Our approximation is based on the assumption that the ratio of sales to value added is the same for all firms that are within the same four-digit SIC group.

Use of the value added production function caused the coefficient of the R&D stock to be non-significant. Tests also failed to confirm that the materials variable adds to the explanatory power of the production function. Consequently, we conclude that the other formulation of the

production function is superior to the value-added form, given the poor quality of the materials purchased data. This conclusion may be re-examined if better materials purchased data become available.

R+D Demand Equation

The R+D equation is derived from the relation of R+D to the production of technical knowledge and the subsequent influence of that knowledge on sales. The formal derivation of the equation used in our regressions is given in Appendix E. Two forms of the R+D equation were used. The first corresponds to a lagged adjustment model in which R+D at the firm level adjusts over time to the desired or optimal firm level. In the second formulation, the adjustment is assumed to take place between the actual and desired level of R+D intensity, where R+D intensity is defined as the ratio of R+D to sales. As before, the models are specified in log-log form. The form of the first equation is:

$$\ln R_t = \beta_0 + \beta_1 \ln R_{t-1} + \beta_2 g_t + \beta_3 \ln S_t + \epsilon_t \quad (5-8)$$

where

R_t = R+D expenditures in year t (millions of dollars),

g_t = the firm's expected rate of growth of future production,
and

S_t = sales in year t (millions of dollars).

In the second form of the R+D equation,

$$\ln(R_t/S_t) = \beta_0 + \beta_4 \ln(R_{t-1}/S_{t-1}) + \beta_2 g_t + \epsilon_t \quad (5-9)$$

The variable g_t is not observable--no company data exist for the expected rate of growth of output. In our estimates of the R+D equation we used a surrogate the actual growth rate of production over the next year as a surrogate for g_t . This assumes that the firm has so-called

"rational expectations" and can forecast its growth with an error whose average value over time is zero.* The variable g , the expected rate of growth in production, is thus a true value plus an error term. This produces the errors-in-variables problem often encountered in regression analysis. Consequently, an ordinary least squares regression will produce a biased estimate of the coefficient of g_t . For this reason we use instrumental variables in the estimation of the equation to obtain an estimate of g_t whose error term is uncorrelated with R_t . The value of g is first estimated as

$$g_t = b_0 + b_1 g_{t-1} + b_2 \bar{R}_{t-1} + b_3 S_{t-1} + b_4 L_{t-2} + b_5 C_{t-2},$$

The resulting predicted values of g_t are then used in the regressions of the R+D equations.

The results of the R+D equations are given in Table 5-5. The first shows R+D expenditures as a function of lagged R+D, expected growth of production, and sales. The first equation has a very high R-squared, which should not be surprising, given the use of firm-specific constant terms and the typically high degree of correlation of R+D expenditures with lagged R+D expenditures and sales, as is reflected in the high significance of their respective coefficients. These results do not imply much support for any particular model of R+D demand. The growth rate term b_2 is not statistically significant in this estimate.

*See John Muth "Rational Expectations and the Theory of Price Movements", *Econometrica*, 1961. Of course, this is not the only way to model firms' formation of expectations.

The R+D intensity equation also has a good fit for similar reasons. In this case, the coefficient of the expected growth term is strongly significant. Further investigation is needed to determine why this different result occurs.

The coefficient estimates of the two equations can be tested to determine whether they imply reasonable values for the parameters of the underlying theoretical model. If so, this lends greater credibility to the model, and, in particular, makes it more plausible to use the model to simulate TSCA impacts by altering the values of the parameters in ways that TSCA is assumed to affect them to see the resulting impact on the demand for R+D.

As is discussed in Appendix E, the coefficient of lagged R+D is related to the rate of adjustment between actual and desired R+D expenditures, γ , as follows:

$$\beta_1 = 1 - \gamma$$

The average lag between R+D expenditures and the returns to R+D is

$$L = \frac{1 - \gamma}{\gamma} + \theta$$

where θ is the gestation lag between the time research is undertaken and its output is used in the production process of the firm.* Given the results in Table 5-5, we have:

$$L = \frac{\beta_1}{1 - \beta_1} + \theta = (2.03 + \theta) \text{ years.}$$

*See A. Pakes and M. Schankerman, "The Rate of Obsolescence of Knowledge, Research Gestation Lags, and the Private Rate of Return to Research Resources," Harvard Institute for Economic Research Discussion Paper 659, October 1978.

Table 5-5
R+D Equation Regression Results

R_t = R+D expenditures in year t (millions of dollars, deflated)
 i = Index denoting i th firm
 g = Expected growth rate of sales
 S_t = Sales in year t (millions of dollars, deflated)

$$1) \ln R_t = \beta_{0i} + \beta_1 \ln R_{t-1} + \beta_2 g + \beta_3 \ln S_t + \epsilon_t$$

$$\beta_1 = 0.670 \text{ (0.031)}$$

$$\beta_2 = 0.215 \text{ (0.347)}$$

$$\beta_3 = 0.173 \text{ (0.056)}$$

$$-0.97 \leq \beta_{0i} \leq 0.346$$

$$R^2 = 0.99$$

$$F \text{ ratio} = 3,736 \quad d.f. = 463$$

$$2) \ln(R_t/S_t) = \beta_{0i} + \beta_4 \ln(R_{t-1}/S_{t-1}) + \beta_2 g + \epsilon_t$$

$$\beta_4 = 0.726 \text{ (0.029)}$$

$$\beta_2 = 0.685 \text{ (0.140)}$$

$$-1.58 \leq \beta_{0i} \leq -0.76$$

$$R^2 = 0.99$$

$$F \text{ ratio} = 5,412 \quad d.f. = 455$$

Notes: Standard errors are shown in parentheses.
 The range of intercept coefficients for firms is shown.
 Degrees of freedom are indicated by "d.f."

Similarly, for the intensity form of the equation,

$$L = \frac{\beta_4}{1 - \beta_4} + \theta = (2.65 + \theta) \text{ years.}$$

The theoretical value of the coefficient on expected growth in the first equation is shown in Appendix E to be given by:

$$\frac{\beta_2}{\gamma} = \frac{1}{r + \delta} + \theta$$

where

r = the discount rate,
 δ = the rate of decay of the innovation benefits, and
 θ = the gestation lag between development and commercialization.

If $r = 0.15/\text{yr}$, $\delta = 0.25/\text{yr}$, and $\theta = 1$ year, reasonable guesses of the probable true values, then

$$\frac{1}{r + \delta} + \theta = 3.5 \text{ years}$$

For the intensity form of the equation, the estimated parameters show

$$\frac{\beta_2}{\gamma} = \frac{.685}{.274} = 2.5 \text{ years}$$

which is in line with the value computed above. Thus, for the intensity form of the R+D equation, the estimated values of γ and β_2 are in line with a priori theoretical expectations. For the first equation, this formula yields a value of .65, considerably below the theoretical value. This is not surprising given the low significance of the coefficient estimate in that equation.

We can also examine the coefficients directly for information regarding the probable behavior of firms. Consider, for example, the intensity form of the equation. The equation has coefficients of 0.726

and 0.685 associated with log lagged sales intensity and expected production growth, respectively. This implies that a 1 percent larger R+D intensity last year will be associated with 0.726 percent greater R+D intensity this year. Similarly, a 1 percent greater expected growth rate will yield a 0.685 percent greater R+D intensity.

As with the production function, we can compute the marginal change in R+D that should accompany an increase in the lag between R+D expenditures and the realization of their benefits for the firm. To do so requires the use of the derivation of the R+D equation in Appendix E. In the last page of that appendix it can be seen that the lag, θ , affects the value of the coefficients β_0 , β_1 and β_4 . If we use the intensity form of the equation then the marginal effect on R+D of a change in θ is, given $g = .13$, $r = .15$, $\delta = .25$:

$$\frac{d \ln(R/S)}{d\theta} = \gamma(g - r - \delta) + \gamma g = \gamma(2g - r - \delta) = -0.04$$

Thus, an increase in the lag would be expected to lower R+D intensity.

Section 6

Using the Innovation Relations

If the impact of TSCA is large, its effects will relate to each of the three innovation equations. The main impact of TSCA will be on the costs and benefits of producing an increment of knowledge. The benefits of research to the firm may be diminished due to the decreased probability of bringing a new chemical to the manufacturing and distribution stage. TSCA testing requirements and other regulations may increase costs and increase the gestation lags at different stages of a product's development. Increased uncertainty may also inhibit innovation activity.

The equation for R+D demand provides an estimate of the amount of R+D that is expected to occur. Significant deviations of actual R+D expenditures from the expected R+D would be cause to examine carefully whether TSCA is responsible for the change. The relation of patent generation to R+D expenditures can also be observed over time to determine whether the future behavior of firms conforms to the patent production relation. If changes are observed they may be due to increased costs of R+D. Also, the production function can be used to derive the gross rate of return to R+D. Changes in those returns may occur as a result of TSCA actions.

In each of the above instances, errors in our data and uncertainties in the equations imply that the deviations between expected and observed values will have to be large in order to be certain that a change in behavior has occurred. If such a change is observed, other possible causes that are not related to TSCA, such as changes in other legislation, must be considered. Also, TSCA may affect different types of research

differently, e.g., process-related research may thrive relative to product-related research. These and other factors are not accounted for by our equations and data. For this reason the use of the equations is limited and, as is discussed below and in greater detail in Section 7, refinements of the data and equations are desirable.

All of the equations are subject to error. As is stated above, the accuracy of the equations may be insufficient to identify successfully changes in the chemicals industry caused by TSCA. The standard errors of the equations provide a guideline regarding the limits within which the time coefficients fall. Given a large enough sample, with 95 percent confidence the true coefficient lies in an interval bounded by the estimated coefficient ± 1.96 standard errors.

Table 6-1 shows the confidence intervals for the dependent variable for the equations estimated in Section 5. The confidence intervals are obtained by multiplying the mean standard error of the regression by 1.96. The table also shows the percentage of the confidence intervals above and below the mean of the dependent variable. The equations presented in Section 5 all employed firm-specific dummy variables, which gave them very high explanatory power. These dummies may not be useful in estimating industry-wide impacts, so the results for equivalent equations without the firm-specific dummies are presented as well.

The patent equation shows the greatest amount of error, with a ± 53 percent confidence interval if firm dummies are not allowed. On the other hand, industry-wide impacts could show average impacts over a large number of firms, so the aggregate error would be much less. The production function and R+D expenditure equations show much less error, with

Table 6-1
Confidence Intervals of Estimated Equations

<u>Dependent Variable</u>	<u>Mean</u>	<u>95 Percent Confidence Interval*</u>			
		<u>With Firm Dummies</u>		<u>Without Firm Dummies</u>	
		<u>Value</u>	<u>Percent</u>	<u>Value</u>	<u>Percent</u>
1. Patent Equation (1)					
ln (Patent Applications)	3.00	.74	23	1.56	53
2. Production Function (1)					
ln (Sales)	5.31	.27	5.1	.62	11
3. R+D equation					
a. ln (R+D expenditures)	2.31	.29	13	.35	15
b. ln (R+D exp./Sales)	-3.60	.33	9.2	N/A	N/A

*Ninety-five percent confidence interval = $1.96 \times$ standard error of regression.

confidence intervals of 11 and 15 percent, respectively, even without firm dummies. The R+D intensity equation performs slightly better than the R+D expenditure form. Nevertheless, these errors are large enough so that their combined effect is likely to be at least the same order of magnitude as those of TSCA impacts.

Our equations are all estimated using firm-level data. It is desirable to extrapolate these results to the chemicals industry as a whole in order to use the equations for the baseline. The equations in their same forms could be estimated using aggregate industry data, if such data were available for a sufficiently long period. Since the data are not available, we have used the firm-level equations to make industry projections. This can result in errors because the industry relationships will not necessarily be the same as the firm-level ones.

The source of the difference between the firm-level and industry relationships is in the borrowed knowledge illustrated in Figure 4-1 of Section 4. Firms not only benefit from their own research, but also acquire knowledge from the research of other firms and institutions. A firm will usually fail to capture all of the benefits associated with an invention of a product. Other firms will attempt to exploit the invention or derivatives of it. The result is that a dollar spent on research by a firm produces benefits for the industry that are greater than those for the firm. Consequently, the coefficients of the R+D stock in the patent and production equations will be higher for the industry estimates than they are for the firm-level estimates. The industry R+D demand is simply the sum of the demands by firms and thus the R+D equation does not exhibit this bias.

R+D Baseline

We have applied the intensity form of the R+D equation to aggregate data for the National Science Foundation categories, "Industrial Chemicals" and "Other Chemicals." The results are given in Table 6-2 and are plotted in Figure 6-1. The first column of Table 6-2 gives the actual value of R+D intensity (R+D as a percentage of sales) reported by the National Science Foundation. The other two columns show the predicted value of R+D intensity computed using the R+D equation given in Table 5-5:*

$$\ln(R_t/S_t) = -1.05 + 0.726 \ln(R_{t-1}/S_{t-1}) + 0.685g_t$$

The second column of Table 6-2 gives one set of predicted values of R+D expenditures. The 1971 through 1979 predicted values of R_t/S_t are computed using values of R_{t-1}/S_{t-1} from column one and the actual growth in production g_t as reported by the DRI chemicals production index. For years beyond 1979, the DRI "Trendlong" projection of production growth is used for the value of g_t . The "Trendlong" projection assumes steady long-term economic growth without major fluctuations. For years beyond 1980, the lagged predicted value of R_t/S_t is used for R_{t-1}/S_{t-1} .

The third column of Table 6-2 gives the "Cyclelong" predicted value of R+D expenditures. The "Cyclelong" projection assumes significant fluctuations in economic growth due to business cycles or periodic shocks to the system. It is computed in the same way as column two using the DRI

*The constant term is an average value of the firm-specific constant terms.

**Trendlong and Cyclelong are projections of the economy, published in U.S. Long-Term Review, Data Resources, Inc., Winter 1978.

"Cyclelong" projection instead of the "Trendlong" projection of growth. The "Cyclelong" column is identical to the "Trendlong" column until 1980 since up to that point both computations of predicted R_t/S_t are made using historical data.

Figure 6-1 is a plot of the three columns. The actual R+D intensity is given only through 1980. The predicted values are given for the entire period. The plot shows that the predicted values track the actual values quite well. The standard deviation of the differences between the actual and predicted values of R+D intensity for the period 1971-80 is .118 or 4.1 percent of the average value of 2.88 for R+D intensity. Almost all of the turns in actual R+D intensity also occur in predicted R+D intensity. Beyond 1980 the predicted values are based on predicted values of production growth and on lagged predicted values of R+D intensity. Thus, the confidence in the prediction decreases as the year approaches 1990.

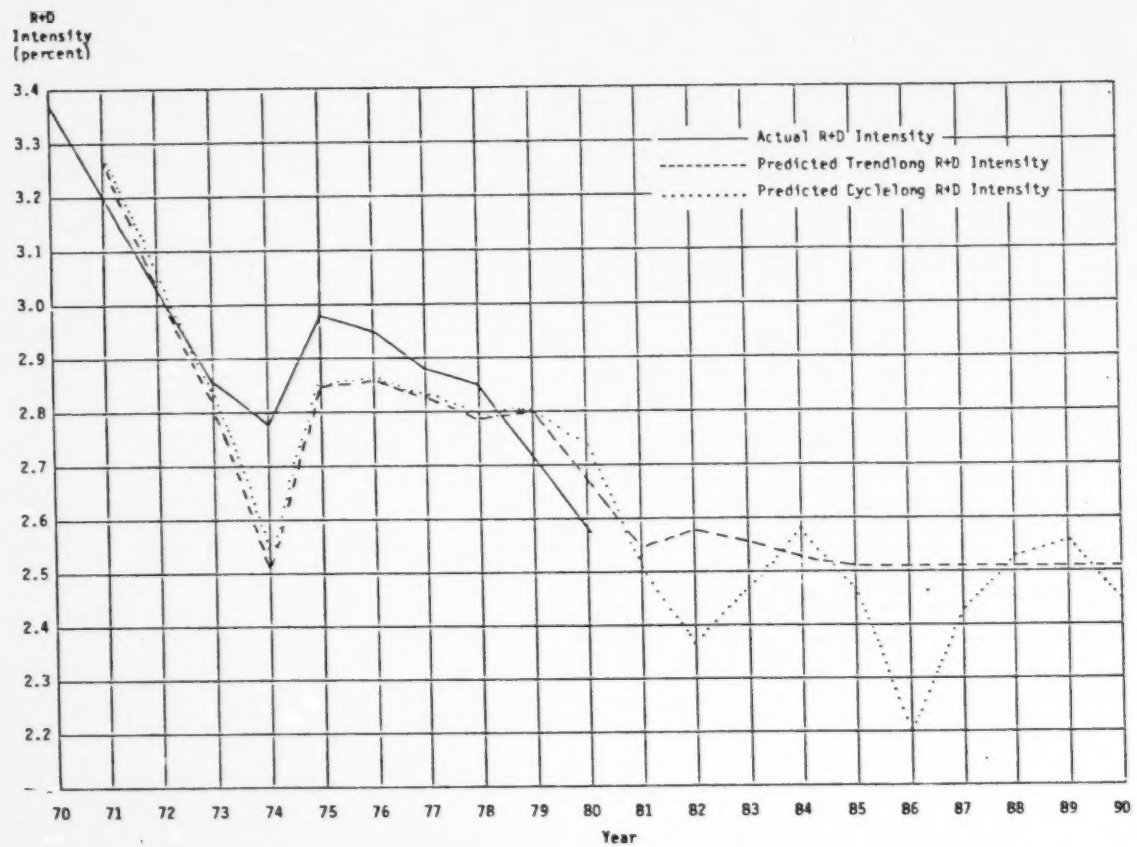
Similar exercises could be performed using the other innovation equations either singly or in combination to provide a set of baseline predicted values. These values may be compared with observed values. In addition, simulation exercises can be made to produce ex ante estimates of TSCA impacts using the TSCA "knobs" in the innovation model described in Section 4. Proposals along these lines are given in Section 7.

Table 6-2
Actual and Predicted R+D Intensity

<u>Year</u>	<u>(1) Actual R+D Intensity</u>	<u>(2) Predicted "Trendlong" R+D Intensity</u>	<u>(3) Predicted "Cyclelong" R+D Intensity</u>
1970	3.37	-	-
1971	3.20	3.27	3.27
1972	3.03	3.03	3.03
1973	2.86	2.82	2.82
1974	2.78	2.51	2.51
1975	2.98	2.85	2.85
1976	2.95	2.86	2.86
1977	2.88	2.83	2.83
1978	2.85	2.79	2.79
1979	2.71	2.80	2.80
1980	2.58	2.67	2.74
1981		2.55	2.51
1982		2.58	2.37
1983		2.56	2.47
1984		2.53	2.58
1985		2.51	2.47
1986		2.51	2.21
1987		2.51	2.43
1988		2.51	2.53
1989		2.51	2.56
1990		2.51	2.45

Note: All values are R+D expenditures as a percentage of sales.

Figure 6-1
Actual and Predicted R+D Intensity



Section 7

Future Research

The formulation and estimation of the patent equation, production function, and R+D equation were guided and constrained by the current information regarding TSCA. Our aim was to construct a baseline and a model with which TSCA regulatory actions can be assessed. Because the mandate of TSCA is broad, those future actions may take a number of forms, e.g., the banning of a group of chemicals. Without specific information regarding the TSCA action, it is impossible to formulate a baseline model that links the regulatory actions to useful innovation indicators of the chemicals industry.

Our research was also guided and constrained by the chemicals industry data that are available. We used a firm-level approach because there are data available on R+D expenditures for publicly owned firms and we employed patent counts as an innovation indicator because the data are available from the Office of Technology Assessment and Forecasting.

The modeling work described in the previous sections has provided a promising beginning but a good deal of further work needs to be done to develop a model with a sufficiently good data base and level of disaggregation to provide a basis for analyzing TSCA impacts. This section proposes further work along three major lines:

- 1) Data Collection Effort: This includes increasing the coverage of the data set to include smaller firms, obtaining chemical line financial data for large diversified firms, obtaining additional measures of innovation outputs, and obtaining separate estimates of product and process innovation. A survey may be included in this effort;

- 2) Modeling Effort: This includes refining the existing three equation model, e.g., identifying different behavioral patterns among different segments of the industry, and developing a model which includes the choice between product and process innovation; and
- 3) Impact Methodology: Develop a methodology to determine aggregate industry impacts and use the model in simulation exercises to predict TSCA impacts using the TSCA-related parameters identified in the model.

The following sections discuss these efforts in greater detail.

Data Collection Effort

Although we believe the three equation system described in the previous section provides a useful framework for analyzing TSCA impacts, the proposed data collection effort will substantially increase the usefulness of the analysis. The data collection effort has four main goals:

- increase the coverage of the data set, with particular emphasis on getting more observations on smaller firms;
- obtain financial data for chemical lines of business of firms rather than overall firm aggregates;
- obtain additional measures of innovation; and
- obtain disaggregated estimates of process and product innovation.

Expand Data Set

The analysis presented thus far was based on a sample of 48 firms. The basis for selecting those firms will be reviewed. All feasible avenues will be explored to expand the data set to include a representative sample of firms with respect to size, major product line, degree of specialization and degree of innovative behavior. For example, the CSMA study notes the important difference in impacts due to PMN's

between ingredient suppliers and product manufacturers, and between large and small firms. Data on small firms will be difficult to obtain, since 10-K data are about the only publicly available source of financial information on firms, and they are limited to publicly-held firms, which tend to be large.

Obtain Line of Business Financial Data

The analysis was based on company level financial data. Since many major chemical companies have major operations in a number of industries, it is impossible to identify intra-company variations in innovative behavior in each line of business without more disaggregated data. Two data sources provide breakdowns of company financial data (including R+D expenditures) by major line of business: the FTC Line of Business Survey, and the PIMS data base at the Strategic Planning Institute in Cambridge, Massachusetts. The Line of Business Survey data base covers about 450 companies, including the 250 largest manufacturing companies (in terms of sales) and another 200 companies drawn from the 1000 largest manufacturing companies to ensure adequate coverage of the major industries. The data cover the years 1974 to 1977. This should not prove too much of a limitation, since large firms are more likely than small firms to span several industries.

Both data bases are confidential, so approval for access is required. Based on preliminary discussions with the FTC, this should not be a problem for the kind of study proposed. The availability of the PIMS data is more questionable, since the Strategic Planning Institute is a private organization whose policy is to limit data to member companies or academics. However, in preliminary discussions, they did not deny our

request out of hand, so this avenue is worth pursuing, as well. In all likelihood, the coverages of the FTC and PIMS data bases do not differ much.

Obtain Other Innovation Measures

The analysis used patent applications as the measure of increments to knowledge. The question arises of how accurate patents are as indicators of the development of NCE's, since the latter are the target of the PMN regulation. There may be significant variation over time and across firms in the "propensity to patent" relative to actual innovation activity. Therefore, it will benefit the analysis a great deal to develop other measures of innovation. Not only will the other measures shed light on the reliability of patent data, but there are econometric techniques which allow multiple measures of innovation to be used jointly to extract the maximum amount of information. (See the section on methodology below.) The post-TSCA behavior of the various innovation measures can be compared with the PMN's submitted to EPA to see how closely related they are. Econometric techniques are also available to screen out the "noise" due to random variation of firms' propensity to patent.

The major source of publicly available data other than patents on new chemical entities is chemical directories such as SRI's Chemical Producers Handbook. A year to year comparison of chemicals produced by companies in the sample will provide some measure of product innovations. There are a number of problems with such data sources, however. Coverage of chemicals is sometimes spotty, and the criteria for inclusion of chemicals in the handbooks occasionally change. It also may be difficult to distinguish genuine innovations from the first production of an existing chemical by a

certain company. Despite their noisy quality, these data will provide additional information on innovation.

Classify Innovations by Product or Process

The analysis was based on simple patent counts. However, one major effect of PMN and other TSCA regulations may be to shift innovative activity from new products to process modifications, since the latter are not subject to TSCA requirements. Based on data already obtained, patents will be classified as products or process for firms in the sample. Preliminary inspection of the patent data base indicates that it will be possible to classify many patents in this way, although it may not be possible for all patents. As is described in the section on methodology below, this data will be used to estimate revised forms of the knowledge production function and R+D equations which explicitly incorporate the tradeoff between product and process innovation. The revised specification will allow estimates of any shift in innovative activity resulting from the TSCA-induced added costs of product innovation.

Survey

Acquisition of additional data by a survey of the chemicals industry is desirable in order to develop a better historical record of innovation-related variables. The data sought from a survey include the following, on an annual basis:

- counts of new chemical entities developed (e.g., R+D objective attained);
- counts of new chemicals brought into commercial production;
- ratio of sales of new chemicals to total sales of all chemicals;

- ratio of R+D expenditure on chemicals and chemical processes to total R+D expenditures;
- allocation of R+D expenditures (chemical related) to: a) new products; b) new chemical processes; c) new product and new process; and d) other, e.g., improvements of existing products.

The design of a suitable survey would, of course, include rigorous definition of these terms and a testing of the survey format to assure uniform interpretation by the chemical firms. In addition to greater detail about innovation variables, the survey should also improve the historical record by acquiring information from small firms and specialty chemical firms.

Model Formulation and Estimation

Two main phases of the modeling work are proposed: (1) refinement of the existing equations using alternative specifications, the expanded data set, and separate analysis of different firm groups; and (2) development and estimation of revised equations which specify the tradeoffs between product and process innovation. The latter represents an important step forward because of the differential impact of TSCA on the two kinds of innovation. Moreover, since the data are already on hand to identify product and process innovation, this step is feasible.

Refine Existing Equations

The data collection effort described in the previous section will provide a data base which is a more representative sample of the industry, has more innovation information, and has more industry-specific financial information. This enriched data base will allow the following refinements of the equations to be made.

Segregate firm groups. Firms will be classified according to their size, major product line, degree of innovation activity, and other relevant variables. Tests will be made to determine whether the firm groups differ significantly in their innovative behavior and, implicitly, in their response of TSCA requirements. This will be done for all three equations.

Firm-specific vs. time-varying components. The data base includes pooled cross section and time series data. It is useful to identify the relative explanatory power of firm-specific constant terms and the variation over time of the right hand variables. Various techniques are available to make this decomposition, including using firm averages or moving averages. This decomposition will also make it easier to compare different lag structures and other variations in the specification of the three equations. Otherwise, the firm-specific constant terms overpower the time-varying component, making the effects of different specifications on R^2 undetectable.

Measures of innovation. The expanded data base will include other measures of innovative outputs besides patents such as changes in chemical directory listings. These can be used to determine the correlation of patents with other innovation measures, and hence their stability over time and across firms. In addition, econometric techniques can be used to exploit the information contained in various measures of innovation to obtain a better estimate of, say, the effect of increments to knowledge on factor productivity.

These techniques are referred to as "unobservable variable" methods.* The general approach is to estimate a set of simultaneous equations which includes both the hypothesized underlying relationship involving the unobservable variable (innovation) and the relationships between the unobservable behavior and its proxies. Some special assumptions about relationship between the unobservable variable and the proxies must be made, e.g., uncorrelated errors, to enable the combined information provided by the various proxies to be exploited.

Model with Product/Process Tradeoff

The tradeoff between process and product innovation can be incorporated into the knowledge production function equation by postulating that R+D expenditures can be used to produce two kinds of increments to knowledge, $\dot{K}_1$ and $\dot{K}_2$. The relationships could be captured by a multi-output function such as the constant elasticity of substitution (CES) form. The belief that process and product innovation are substitutes rather than complements implies certain restrictions about the coefficient estimates that can be tested. Also, the econometric procedure will have to account for the fact that actual measures of process and product innovation are error-laden proxies for increments to knowledge. These points and the structure of the model are discussed in greater detail in Appendix F of this report.

The specification of the knowledge production function is also incorporated into the R+D demand equation, since it reflects the

*A description of this approach is contained in Pakes and Griliches (1980).

productivity of R+D. The details of the specification have not yet been worked out, but they would be analogous to those for the simple innovation model presented in this report.

The production function equation will also be re-estimated with two separate stocks of knowledge representing product and process innovation or inputs.

All the estimation refinements described in the previous subsection will also apply to the revised model.

Impact Methodology

The focus of the impact methodology will be on ex ante analysis using outside estimates of direct TSCA impacts on the costs of innovation. This approach is dictated by the great difficulty of causally attributing any ex post variation in observed innovation variables to specific TSCA requirements, even though there may be a strong statistical correlation. In addition, this approach provides a basis for comparing the results of different studies of TSCA impacts. The ex ante direct TSCA impacts will be converted into changes in the TSCA-related parameters of the innovation equations: the productivity of R+D expenditures (based on R+D cost increases, increased uncertainty, or reduced probability of success); and increased R+D lag or gestation lag. In the case where product and process innovation are specified separately, TSCA impacts will also be converted to a change in the relative cost of product and process innovation.

The estimated equations describe firm behavior. Since both innovative behavior and TSCA impacts will vary by firm depending on size, innovative behavior and product line, a method must be developed to aggregate these

firm level impacts to the industry level. This requires three pieces of information: the composition of the industry by firm type; specification of differences in innovation by firm type; and estimates of TSCA impacts by firm type. The composition of the industry will be fairly straightforward to determine from publicly available data including the U.S. Census of Manufactures and industry association data. Differences in innovation behavior will emerge from the modeling work described in that section. Differences in direct TSCA impacts will be taken from a variety of studies, including those of the CMA, CSMA, and ICF, Inc.

This implies the following general procedure for measuring industry-wide impacts:

- 1) Determine direct TSCA impacts for each type of firm;
- 2) Calculate resulting impacts on R+D expenditures, innovation outputs and productivity for each firm type; and
- 3) Multiply the results for each firm type by the appropriate weights to obtain overall impacts for the industry.

The modeling of the effect of TSCA on the choice between product and process innovation entails some extra steps that cannot be described in detail until the specifications of the three equations with the product/process tradeoff are determined. In broad terms, the problem is to identify the factors which determine the observed equilibrium between product and process innovation. An equilibrium implies equality of the relative "prices" of the two kinds of innovation with their marginal rate of transformation as specified in the knowledge production function. Given a change in the relative costs of the two kinds of innovation, this implies that a new demand/supply equilibrium and a new set of implied "prices" will result from TSCA impacts. The specification of the

production side is already given by the knowledge production function; the problem is how to specify the response of the demand for innovation to the change in relative costs.

Summary

The major strengths of the impact methodology described here are:

- it relies on publicly available data rather than surveys, thus making it easier to track the innovation variables over time;
- it provides an explicit link between TSCA impacts, the demand and supply of R&D inputs, the resulting impacts on the level of R&D and the stock of knowledge, and the subsequent impact on total factor productivity;
- it takes into account the existence of different firms in the industry whose innovation behavior depends on such factors as size and market orientation; and
- it provides a framework for the comparison of predictions of direct TSCA impacts from a variety of sources.

The major weaknesses lie not in the three-equation framework itself, but in the question of data availability. It will be difficult to rely on patent data unless they can be shown to correlate reasonably well with other measures of innovation. It will be difficult to obtain financial data on small firms. On the other hand, we can be reasonably confident of success in the area of obtaining financial data at the line of business level and of expanding the model to handle the choice between products and processes, since the data are available.

APPENDICES

APPENDIX A
BIBLIOGRAPHY

BIBLIOGRAPHY

- Arthur D. Little, Inc. 1978. Impact of Proposed Premanufacturing Notification Requirements. U.S. Environmental Protection Agency, EPA 230/2-12-78-005.
- Baily, Martin Neil. 1972. "Research and Development Costs and Returns: The U.S. Pharmaceutical Industry." Journal of Political Economy, 80 (1), January-February 1972, pp. 70-85.
- Boston Consulting Group. 1973. Experience Curve - Reviewed.
- Bozdogan, Kirkor. 1979. Formal Analytical Approaches for Measuring the Economic Impact of the Toxic Substances Control Act (TSCA) on the Chemicals and Other Industries. Technical paper.
- Cavallito, C.J. "Interactions of Science, Economics and Politics in Drug Discovery, Development and Delivery." Drug Development Communications, 1 (4) 1974-1975, pp. 259-285.
- Charles River Associates, Inc. 1980. Innovation, Competition, and Government Policy in the Semiconductor Industry.
- _____. 1980. Innovation, Competition, and Government Policy: A Framework for Analysis.
- _____. 1981. Productivity Impacts of Government R&D Laboratories: The National Bureau of Standards' Semiconductor Technology Program -- A "Production Function Approach".
- Chemical Marketing Reporter, The. 1980. Chemical Managers View '80's As Tough Decade for Industry to Introduce It's New Products. pg 57.
- Clauser, H.R. 1974. Progress in Assessing Technological Innovation. Technomic Publishing.
- Data Resources, Inc. 1978. U.S. Long-Term Review. Winter, 1978.
- _____. 1981. "Baseline Variables to Measuring the Cumulative Impacts of TSCA on the U.S. Chemicals Industry and on the National Economy."
- de Haen, Paul. 1976. "Effect of Legislation on the Introduction of Drugs -- Is There a Drug Lag?" Drug Intelligence and Clinical Pharmacy, 10 (2) February 1976, pp. 86-93.
- Denver Research Institute. 1976. Federal Incentives for Innovation: Why Innovations Falter and Fail: A Study of 200 Cases.
- Diebold Group, Inc., The. 1973. An Analysis of Factors Affecting private Investment in New Products, Processes and Services.

- Dominquez, George S. 1979. The Business Guide to TOSCA. John Wiley and Sons.
- Dun and Bradstreet, Inc. 1981. 1981 Million Dollar Directory.
- Executive Office of the President, Office of Management and Budget. 1972. Standard Industrial Classification Manual 1972. Prepared by the Statistical Policy Division.
- Faust, Richard E. 1979. "The 1962 Drug Amendments: Challenge to the Research Process." American Pharmacy, 19 (4) April 1979, pp. 11-14.
- Fuss, M. and D. McFadden, 1978. Production Economics: A Dual Approach to Theory and Applications, North Holland-Elsevier.
- Gold, Rossegger and Boylan. 1980. Evaluating Technological Innovations. D.C. Health and Company.
- Goldsmith, Maurice. 1970. Technological Innovation and the Economy. Wiley-Interscience.
- Grabowski, Henry G. 1978. "Estimating the Effects of Regulation On Innovation: An International Comparative Analysis of th Pharmaceutical Industry." The Journal of Law and Economics, XXI, (1), April 1978, pp. 133-163.
- _____. 1979. "The Impact of Regulation on Innovation," Food Drug and Cosmetic Law Journal, 34 (10), October 1979, pp. 555-560.
- Grabowski, Henry G. and John M. Vernon. 1977. "Consumer Protection Regulation in Ethical Drugs." The American Economic Review, 67 (1), February, 1977, pp. 359-364.
- _____. 1979. "Substitution Laws and Innovation in the Pharmaceutical Industry." Law and Contemporary Problems, 43 (1) Winter-Spring 1979, pp 43-66.
- Greenberg, Edward, Christopher T. Hill, and David Newburger. 1979. Regulation, Market Prices and Process Innovation: The Case of the Ammonia Industry. Westview Press.
- Griliches, Zvi. "Returns to Research and Development Expenditures In the Private Sector." in New Developments in Productivity Analysis and Measurement by J. Kendrick and B. Vacary.
- _____. 1979. "Issues In Assessing the Contribution of Research and Development to Productivity Growth." Vol. 10, No. 1. The Bell Journal of Economics.
- Griliches, Zvi and Dale Jorgenson. 1967. "The Explanation of Productivity Change." Vol. 34. Review of Economic Studies.

- Hill, Christopher T., ed. 1979. Federal Regulation and Chemical Innovation. ACS Symposium Series 109, American Chemical Society, Washington, D.C.
- Hill, Christopher. 1981. "Comments on the February 1981 Methodology Work Plan Report on the TSCA Project." (Unpublished working paper.)
- Hill, Christopher, Andrews, A.A., Frenkel, Heaton, Mitchell, C.S. and W.C. Priest. 1980. Supporting Innovation: A Policy Study. U.S. Environmental Protection Agency, EPA 560/12-80-002.
- Iverstine, J.C., Kinard, J.L. and W.S. Slaughter. 1978. "The Impact of Environmental Protection Regulations on Research and Development in the Industrial Chemical Industry." Southeastern Louisiana University.
- Jadlow, Joseph M. 1971-71. "Competition and 'Quality' in the Drug Industry: The 1962 Kefauver-Harris Drug Amendments As Barriers to Entry." Antitrust Law and Economics Review, 5 (2) Winter 1971-71, pp. 103-123.
- Jondrow, James M. 1972. A Measure of the Monetary Benefits and Costs to Consumers of the Regulation of Prescription Drug Effectiveness. Madison, Wisconsin, Microfilm, 1972.
- Knight, Kenneth E., Kozmetsky, George, and Helen R. Baca. Industry Views of the Role of the Federal Government in Industrial Innovation. University of Texas at Austin.
- Laubach, G.D. 1980. "Federal Regulation and Pharmaceutical Innovation." Proceedings of the Academy of Political Science, 33 (4) 1980, pp. 60-80.
- Leone, Robert A. The Real Costs of Regulation.
- Mansfield, Edwin. 1965. "Technological Changes: Stimuli, Constraints, Returns: Rates of Return From Industrial Research and Development." Vol. 52, No. 2. American Economic Review.
- _____. 1968. The Economics of Technological Change. W.W. Norton and Company.
- _____. 1980. "Research and Development, Productivity, and Inflation." Vol. 209. Science.
- _____. 1980. "Basic Research and Productivity Increases in Manufacturing." Vol. 70, No. 5. American Economic Review.
- Mansfield, E., et al. 1977. Social and Private Rates of Return from Industrial Innovations. John Wiley and Sons, Inc.
- Mansfield, E., et al. 1977. The Production and Application of New Industrial Technology. W.W. Norton and Company, Inc.

Mansfield, Edwin, Teece, David and Romeo Anthonly. Overseas Research and Development by U.S.

McGuire, Thomas, Nelson, Richard and Thomas Spavins. 1975. "An Evaluation of Consumer Protection Legislation: The 1962 Drug Amendments: A Comment." Journal of Political Economy, 83 (3) June 1975, pp. 655-667.

Meta Systems Inc 1981. "Interim Report on Innovation Modeling Effort." (Unpublished working paper.)

_____. 1981. Methodology Work Plan Report. Contract No. 68-01-6134, Cambridge, MA.

_____. 1981. "Methodology Work Plan Report, Elaboration of Research Task I: Development of an Innovation Baseline for the Chemicals Industry." (Unpublished working paper.)

Meyers, Sumner and Donald G. Marquis. Successful Industrial Innovation. National Science Foundation.

Nadiri, Ishaq M. and Mark A. Schankerman. 1981. "Technical Change, Returns to Scale, and the Productivity Slowdown." Vol. 71, NO. 2. AEA Papers and Proceedings.

Robert R. Nathan Associates, Inc. 1978. Net Rates of Return on Innovations.

_____. Net Rates of Return on Innovations. Volume I, Technical Report.

_____. Net Rates of Return on Innovations. Volume II, Case Studies.

National Bureau of Economic Research. 1962. The Rate and Direction of Inventive Activity. Princeton University Press.

National Science Foundation. Industrial R&D Funds in Relation to Other Economic Variables.

_____. 1960-1977. Research and Development in Industry. (Microfiche records).

_____. Funds, 1977. "Scientists and Engineers, January 1978 Technical Notes and Detailed Statistical Tables." NSF 79-313.

_____. 1971. A Review of the Relationship Between Research and Development and Economic Growth/Productivity. William Fellner, et al.

_____. 1971. Research and Development and Economic Growth/Productivity.

_____. 1980. Support of Basic Research by Industry.

- Nelson, Peck and Kalachek. 1967. Technology Economic Growth and Public Policy. The Rand Corporation.
- Nelson, Richard R. and Sidney G. Winter. 1977. In Search of a Useful Theory of Innovation.
- Organization for Economic Co-Operation and Development. 1976. The Measurement of Scientific and Technical Activities.
- Pakes, Ariel and Mark Schankerman. 1980. "An Exploration Into the Determinants of Research Intensity." Working Paper No. 438, National Bureau of Economic Research.
- Pakes, Ariel and Zvi Griliches. 1980. Patents and R+D at the Firm Level: A First Report." Vol. 5, pp 377-381. Economics Letters. North-Holland Publishing Co.
- Peltzman, Sam. 1974. Regulation of Pharmaceutical Innovation. American Enterprise Institute for Public Policy Research, Washington, D.C.
- Phillips, Don I. 1978. Colloquium on R+D Policy. American Association for the Advancement of Science.
- _____. 1979.
- Pindyck, R.S. and D.L. Rubinfeld, 1976. Econometric Models and Economic Forecasts, McGraw-Hill: New York.
- Public Law 94-469. 1976. "Toxic Substances Control Act." 94th Congress.
- Schnee, Jerome, E. 1978. "International Shifts in Innovative Activity: The Case of Pharmaceuticals." The Columbia Journal of World Business, XIII, (1) Spring 1978, pp. 112-122.
- _____. "Regulation and Innovation: U.S. Pharmaceutical Industry." California Management Review, XXII (1) Fall 1979, pp. 23-32.
- _____. 1979. "R+D Strategy in the U.S. Pharmaceutical Industry." Research Policy, 8 (4) October 1979, pp. 365-382.
- Schwartzman, David. 1975. The Expected Return From Pharmaceutical Research. American Enterprise Institute for Public Policy Research, Washington, D.C.
- _____. 1976. Innovation in the Pharmaceutical Industry. Baltimore, The Johns Hopkins University Press.
- Simon, Peter M. 1975. Models of Process-Diffusion and Entry in the United States Chemical Industry. Dissertation in Economics.
- SRI International. 1979. 1979 Directory of Chemical Producers, United States of America.

- Stroetmann, Karl A., ed., Verlog, Brikhauser and Basel und Stuttgart.
1977. Innovation, Economic Change and Technology Policies.
- Teece, David J. 1977. R+D in Energy. Stanford University Institute for Energy.
- U.S. Environmental Protection Agency. 1980. Ecomonic Impact Analysis of Proposed Section 5 Notice Requirements. Support document Part I - Analysis of the Impacts on the Chemical Industry and Part II - Issue Papers.
- U.S. Department of Commerce. 1977. Instructions for Survey of Industrial Research and Development During 1977.
- U.S. Department of Commerce. 1977. Census of Manufacturers.
- Wardell, W., Diraddo, J. and A.G. Trimble. 1980. "Development of New Drugs Originated Acquired By United States-Owned Pharmaceutical Firms, 1963-76." Clinical Pharmacology and Therapeutics, 28 (2) 1980, pp. 270-77.
- A State of the Art Review of the Effects of Regulation on Technological Innovation in the Chemical and Allied Products Industries "CAPI Project". 1975. Volumes I, II and III, Washington University.

APPENDIX B
STRATEGIC GROUPS

STRATEGIC GROUPS OF INNOVATIVE ACTIVITY IN THE CHEMICALS INDUSTRY

The concept of strategic groups has proved useful to analyze the behavior and performance of firms participating in an industry. According to Newman, "the concept of strategic groups turns on interfirm differences perceived by the participants in a market themselves as well as by objective observers."*

We can distinguish two steps in the process of delineating strategic groups: 1) identifying the purpose of the grouping, and 2) identifying the key variables. For any given industry, the identification of the strategic groups may vary between different types of studies. With regard to the chemical industry, Newman's purpose was to explain company profitability. The purpose of the TSCA project is to explain innovative activity. While related to some extent, these two purposes are nevertheless different and call for two different sets of grouping.

To illustrate, we can use the example of the impact of new regulations on the restaurant industry. If the new regulations limit parking time on Main Street, restaurants would be classified according to time spent at the eating place; high-class restaurants would suffer from the new restrictions, while fast-food operations may benefit. If the new regulations consist of price controls and effectively cause shortages of beef, then restaurants would be classified according to type of meat they serve.

Focusing on profitability, Newman segmented the chemical industry by degree of vertical integration and "related core businesses." Focusing on innovative activity, we could segment by product type (commodity vs. specialty) or a limited number of SIC codes, as explained in the following paragraphs.

TYPE I: VERTICAL INTEGRATION AND RELATED CORE BUSINESSES (NEWMAN)

Newman studied 34 4-digit industries drawn from 4 2-digit industries, one of them being SIC 28 -- chemical and allied products. The nature of the strategic groups varied for each of these 34 4-digit industries. Newman was

*Michael Porter, Competitive Strategy: Techniques for Analyzing Industries and Competitors, Free Press, 1980; Howard H. Newman, "Strategic Groups and the Structure-Performance Relationship," Review of Economics and Statistics (August 1978): 417-427; Meta Systems Inc., "Industry Description: Organic Chemicals Industry," Report to the Environmental Protection Agency, May 1980.

interested in the degree of homogeneity within an industry: homogeneity was identified by a concentration of firms within a limited number of strategic groups and was expressed as a single index number for each 4-digit industry. Newman was not interested in identifying the performance of specific strategic groups in terms of profitability; rather, he aimed to prove that homogeneity within an industry leads to higher profits overall.

In his article, Newman described the six groups he identified among the one example he gave -- producers of agricultural fertilizers. His six groups were as follows:

- Specialty producers of agricultural chemicals (SIC 287);
- Integrated producers of petroleum products (SIC 29X);
- Full-line producers of food products (SIC 20X);
- Conglomerates partially based in chemicals (SIC 398/287);
- Full-line producers of ferrous metals (SIC 331); and
- Full-line producers of chemical and allied products (SIC 28X).

We believe that Newman's selection of strategic groups is not directly useful to the TSCA project for two reasons. First, his purpose, measuring overall industry profitability is different from ours; his classification would tell little about innovative behavior or performance. Second, his classification generates an intractable number of strategic groups overall; compressing the data by means of index number of diversity, as he does, would not meet our needs of identifying the performance of each of these strategic groups.

TYPE II: COMMODITY VS. SPECIALTY CHEMICALS

A common grouping used in the chemicals industry is that of commodity and specialty products. Commodity products are specified by their composition and are usually produced in large quantities. Almost by definition, little product innovation can take place in commodities; they are standard staple products. For commodities, the innovative activity is more of the process type. Specialty chemicals are specified by their performance and are usually produced on a small scale. According to the Kline Guide (page 23)*, specialty chemicals are characterized by intense product innovation such as

*Kline Guide to the Chemical Industry, 1977, pp. 21ff.

"(1) development of performance products, either functional synthetics or formulated end-products, (2) patenting new synthetic products."

According to Kline data, specialty chemicals accounted for close to 20 percent of the total sales volume of the chemicals industry (see Table 5). The industry definition used by Kline differs in two ways from that covered by TSCA. First, the largest type of specialty chemicals listed by Kline -- pesticides -- is not covered specifically by TSCA; pesticides represent 4 percent of chemical sales. Second, Kline excludes from its definition the following items that are covered by TSCA: cosmetics, toiletries, household cleaning products, paints, and printing inks. According to ADL* (page III-14), the first three of these items are expected to demonstrate above-average product innovation in the future.

Although Kline provides estimates for industry sales of specialty chemicals, it indicates (at page 21) that few "hard" data are available for this group.* Kline provides no data on profits or innovative activity in this group, although it does detail to some extent the nature of the products included in Table 5.

We believe that the commodity/specialty grouping has two main drawbacks. First, products will be difficult to identify specifically and there may be some tautology between specialty/low volume and commodity/large volume. Second, data may well prove to be impossible to obtain for the specialty chemicals group, as the Kline report indicates.

TYPE III: STANDARD INDUSTRIAL CLASSIFICATION CODES

The 8 3-digit SIC categories listed below have had very different patterns of product innovation.

<u>Chemical Type</u>	<u>SIC Code</u>
Inorganic chemicals	281
Plastics, fibers, and resins	282
Soaps and detergents	284
Paints	285
Organic chemicals	287
Fertilizers (excluding pesticides)	287
Miscellaneous chemicals	289
Petroleum refining	291

*Arthur D. Little, Impact of TSCA Proposed Premanufacturing Notification Requirements, December, 1978.

Table 5

**U.S. SHIPMENTS FOR
SPECIALTY CHEMICALS 1977**
Million dollars

Functional chemical products	
Pesticides, formulated	\$ 2 850
Industrial and institutional cleaners-a	1 485
Plastic materials and resins*	1 050
Water management chemicals-b	655
Automotive chemicals	825
Diagnostic aids	500
Catalysts	365
Synthetic elastomers*	365
Adhesives and sealants*	310
Laboratory chemicals	170
Oil-field chemicals	145
	8 920
Multipurpose additives	
Dyes	690
Organic pigments	445
Plasticizers*	385
Biocides	375
Flavor and fragrances, formulated	360
Thickening and sizing agents	360
Surfactants*	295
Antioxidants	260
Inorganic pigments*	250
Flame retardants	190
Corrosion inhibitors	140
Enzymes	115
Chelating agents	75
Ultraviolet absorbers	35
	3 975
End-use additives-c	
Petroleum additives	1 200
Plastic additives*	945
Food additives	850
Textile specialties	640
Photographic chemicals	470
Plating and metal finishing chemicals	430
Cosmetic additives	370
Rubber-processing chemicals	370
Paper chemicals*	295
Paint specialties*	265
Printing chemicals	110
Foundry chemicals	100
Rotation reagents	95
	\$6 130
Total	\$19.025
Elimination of double counting	\$2 965
TOTAL	\$16.060

*—Excludes commodities

a—Includes some biocides but excludes \$40 million worth of metal cleaners

b—Excludes \$55 million worth of water-treatment chemicals used in oil fields but includes some biocides

c—Includes Functional Chemical products and Multipurpose additives used in these end-uses—for example, includes antioxidants, biocides, flame retardants, organic pigments, plasticizers and UV absorbers used in plastics under Plastics Additives and dyes, flame retardants, surfactants and in cleaners used in textiles under Textile Chemicals. To avoid double counting, eliminated as shown.

*—Estimate by C. R. Kline & Co.

Source: "Kline Guide to the
Chemicals Industry, 1977"

As shown in Table 6, the major product innovations identified by Mansfield fall almost exclusively into SIC 282 (plastics, fibers and resins) and into SIC 286 (organic chemicals). Mansfield noted no major innovation in 5 of the 8 categories, and only 2 innovations in SIC 281 (inorganic chemicals).

The Mansfield data also show a significant reduction in product innovation between the two periods that he analyzed for both organic chemicals and plastics materials; he also shows a doubling of major process innovations between the two periods. A shift from product to process innovation would therefore have occurred between the two periods he covered.

Looking at the same SIC categories prospectively, ADL expects that most product innovation activity will occur in SIC 282 (plastics) and SIC 284 (soaps and detergents) (see Table 7).

ADL expects moderate product innovation on the average in very specialized segments of inorganic and organic chemicals; finally, ADL expects little or no product innovation in paints, fertilizers, petroleum products, and a residual category (SIC 289: miscellaneous chemical products).

In summary neither Mansfield nor ADL see product innovation occurring uniformly along all SIC codes. For both of them product innovations take place mainly in 2 3-digit SIC codes; there has been a shift in the innovative groups over the years, organic chemicals being replaced by soaps and detergents, but both indicate high innovative activity in plastic materials.

We see two advantages to using the SIC code as a basis for segmenting the chemicals industry. First, as demonstrated above, there has been and is expected to be a marked difference between the innovative performance in the various SIC codes. Second, we expect that data will be more readily available for these groups, since the Standard Industrial Classification Manual has very detailed listings of products and many government agencies collect data according to these business lines. For example, the National Science Foundation collects R&D data along these lines (Table 8), the Office of Technology Assessment and Forecast classifies its own data along the same lines (Table 9), and the Department of Commerce also collects data accordingly.*

*Data availability may be limited, however, for some 4- or 5-digit SIC codes; also, diversified or integrated companies are unlikely to publish their financial statements with information classified exclusively or specifically along these lines (see Tables 10, 11, and 12). The product groupings used by Dow Chemical fall mostly along the lines of 3-digit SIC codes; but the groupings used by DuPont and Rohm and Haas typically include 2 or more 3-digit SIC codes.

Table 5

DISTRIBUTION OF MANSFIELD'S MAJOR
PROCESS AND PRODUCT CHEMICAL INNOVATIONS

	SIC Code	Process			Product		
		1930- 1950	1951- 1971	Total	1930- 1950	1951- 1966	Total
281	Inorganic chemicals	6	6	12	2	--	2
282	Plastics, fibers, and resins	--	6	6	32	19	51
284	Soaps and detergents	--	--	--	--	--	--
285	Paints	--	--	--	--	--	--
286	Organic chemicals	13	32	45	10	4	14
287	Fertilizers (excluding pesticides)	1	1	2	--	--	--
289	Not elsewhere classified	--	--	--	--	--	--
291	Petroleum refining	<u>1</u>	<u>--</u>	<u>1</u>	<u>--</u>	<u>--</u>	<u>--</u>
		21	45	66	44	23	67

SOURCES: Derived from Mansfield, The Production and Application of New Industrial Technology, Norton, 1978, Chapter 3; Standard Industrial Classification Manual.

Table 7

EXPECTED PRODUCT INNOVATION ACTIVITY IN CHEMICALS

<u>SIC Category</u>	<u>Product Type</u>	<u>Distribution of 4-Digit Subcategories by Expected Introduction Rate of New Chemicals</u>			
		<u>Large</u>	<u>Moderate</u>	<u>Small</u>	<u>Nonexistent</u>
281	Inorganic chemicals	-----	1*	-----	3
282	Plastics	0	3	0	1
284	Soap and detergents	2	1	0	1
285	Paints	0	0	1	0
286	Organic chemicals	-----	1*	---- (+1)	1
287	Fertilizers (excluding pesticides)	0	0	0	3
289	Miscellaneous	0	0	1	4
291	Petroleum refining	0	0	---- 1 ---	

Notes:

The number of 4-digit categories varies for each of the eight product types listed above.

The (*) indicates that the SIC subcategories consist of items "not elsewhere classified."

SOURCE: Derived from ADL estimates appearing in Impact of TSCA Proposed Premanufacturing Notification Requirements, December 1978, p. III-14.

Table 8

INNOVATIVE ACTIVITY DATA COLLECTED
BY THE NATIONAL SCIENCE FOUNDATION

<u>Item #</u>	<u>For Company Activities As A Whole</u>	<u>For Chemical Activities Separately</u>
4	federal-paid R&D employees company-paid R&D employees	
5	dollars of basic research dollars of applied research dollars of development effort	
8		dollars of basic research in chemistry
9		dollars of R&D for each of these SIC codes: 281 & 286: inorganic and organic industrial chemicals 282: plastics materials 287: fertilizer and pesticides 284, 285, & 289: soaps, paints, and miscellaneous

SOURCE: Derived from Form RD-1, National Science Foundation.



Table 9

INNOVATIVE PERFORMANCE DATA CLASSIFICATION USED BY
THE OFFICE OF TECHNOLOGY ASSESSMENT AND FORECAST

<u>SIC Code</u>	<u>Product Field</u>
281	Industrial inorganic chemicals
282	plastic materials and synthetic resins
284	soaps, detergents, cosmetics and toiletries
285	paints and varnishes
286	industrial organic chemicals
287	fertilizers and pesticides
289	miscellaneous chemicals

SOURCE: Correspondence with the Office of Technology Assessment and Forecast.

Table 10

DOW CHEMICAL

PRODUCT GROUP RESULTS DOW(\$dollars in millions)
Sales

	1976	1975	1974	1973	1972
Chemicals/Metals	\$3,047.9	\$2,747.6	\$2,621.3	\$1,522.3	\$1,169.0
Plastics/Packaging	1,891.3	1,428.9	1,671.3	1,003.9	789.6
Bioproducts/Consumer Products	712.9	711.6	645.7	541.7	445.1
TOTAL	\$5,652.1	\$4,888.1	\$4,938.3	\$3,067.9	\$2,403.7

PRODUCT GROUP ANALYSIS

		Approximate % of Group Sales	
		1976	1975
Chemicals/Metals Group			
231	<i>Inorganic Chemicals</i> Major Products Caustic soda	25	30
	Chlorinated solvents		
	Chlorine		
	Ethylene dibromide		
236	<i>Organic Chemicals</i> Major Products Acetone	30	30
	Ethylene glycol		
	Glycerine		
	Isocyanates and VORANOL polyglycols		
	Phenol		
	Propylene glycols		
	<i>Metals</i> Major Products Magnesium sheet, plate and extrusions	10	10
	Magnesium ingot		
	<i>Functional Products, Oil & Gas Division & Misc.</i>	35	30
281	Major Products & Services Calcium chloride		
	Dow Industrial Service		
	Dowell Division		
236	Ethylene		
	Hydroscience Associates, Inc.		
	Wanda Petroleum		
Total sales (\$ million)		100% \$3048	100% \$2748
Plastics/Packaging Group			
<i>Molding Materials</i>			
282	Major Products Acrylonitrile-butadiene- styrene (ABS)	50	50
	High density polyethylene		
	Low density polyethylene		
	STYRON polystyrene		

Table continued on following page.



Table 10 (Continued)

DCW CHEMICAL

DCW

Operating Income	1976	1975	1974	1973	1972
Chemicals: Metals	\$ 617.4	\$ 690.2	\$ 618.8	\$ 206.3	\$ 156.3
Plastics: Packaging	388.4	298.6	457.7	223.3	154.3
Bioproducts:					
Consumer Products	80.8	91.2	58.1	79.2	47.2
TOTAL	\$1,086.6	\$1,070.0	\$1,134.6	\$ 508.8	\$ 358.0

Plastics/Packaging Group (Cont.)		Uses		Approximate % of Group Sales	
				1976	1975
Coatings and Monomers				40	35
Major Products					
292	Epoxy resins	Coatings, adhesives, laminates			
	Styrene-butadiene latexes	Paper and carpeting			
	Styrene monomer	Production of polystyrene plastic			
	Vinyl chloride monomer	Production of polyvinylchloride plastic			
Plastic Products				10	15
Major Products					
30	Polyethylene film	Industrial packaging, agricultural use			
	Polystyrene film and sheet	Functional and decorative packaging			
	STYROFOAM polystyrene foam	Insulation, floral and craft uses			
	SARAN film	Commercial packaging			
Total sales (\$ millions)				100% \$1891	100% \$1429
Bioproducts and Consumer Product Group				45	50
Health Care Products and Services					
Major Products & Services					
293	Bio-Science Enterprises	Diagnostic services			
	Diagnostic products and equipment	Medical laboratory tests			
	NOVAHISTINE products	Cough and cold preparations			
	RIFADIN and RIFOCIN antibiotics	Broad spectrum antibiotics used primarily for TB treatment			
Agricultural Chemicals				45	40
Major Products					
2979	COYDEN and ZOMIX	Treatment of poultry disease			
	Coccidiostats	Broad range insecticide			
	DURSBAN insecticide	Weed and brush control			
	Phenoxy herbicides	Weed and brush control			
	TORDON herbicide			10	10
Consumer Products					
Major Products					
30	DOW Bathroom Cleaner	Household use			
	HANDIWRAP plastic film	Household plastic film			
	SARAN WRAP plastic film	Household plastic film			
	ZIPLOC bags	Food storage			
Total sales (\$ millions)				100% \$713	100% \$711

SOURCE: Dow Chemical Annual Report.

Table 11

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Charles
River
Associates

DUPONT PRODUCTS

		U.S. Sales (millions \$)	
		1977	1975
287	Biochemicals: Crop protection chemicals including herbicides, fungicides, insecticides, nematocides, and seed protectants.	413	337
283	Animal feed supplement.		
	Pharmaceuticals.		
282	Fabrics & Finishes: Acrylic, alkyd, polyester, fluorocarbon, urethane, and other finishes.	610	533
30	Acrylic, epoxy, fluorocarbon, and polyimide resin coatings and composites for electrical and structural purposes.		
284	Filled acrylic building products.		
	Synthetic elastomer coated fabrics and sheeting.		
	Waxes and polishes, radiator chemicals, and oil and gasoline additives.		
	Cellulose sponge products.		
	Industrial training programs and consulting services.		
	Industrial hygiene instruments.		
281	Chemicals, Dyes and Pigments: Basic chemicals, intermediates, and solvents including acids, amines and derivatives, aniline, butanediol, cyanides, formaldehyde, inorganic salts, methanol, peroxides, silicates, sodium, and tetrahydrofuran.	1350	1217
286	Titanium dioxide white pigments, inorganic and organic color pigments, zircon and staurolite heavy mineral sands, and ferric chloride.		
287	Dyes and organic chemicals for textiles, paper, leather, and other basic industries.		
286	Specialty chemicals including catalysts, chrome complexes, colloidal silica, electroplating products, galvanizing fluxes, and reagents.		
	Catalytic fume abatement systems.		
	International: See principal consolidated and affiliated companies listed above.		
282	Petrochemicals: Intermediates and solvents including acrylonitrile, acetonitrile, adipic acid, dibasic esters, and dimethyl terephthalate.	1776	1551
286	Fluorinated solvents and chemicals, refrigerants, blowing agents, fire extinguishants, and propellants.		
286	Antiknock compounds and other additives for the petroleum industry.		
289	Explosives products including water gels, ammonium nitrate-based blasting agents, blasting accessories, and specialties. Industrial diamonds, explosively clad metals, and resin-anchored rock bolts.		
	Photo Products: X-ray, graphic arts, and engineering reproduction films, chemicals and processing equipment.	890	739
	Printing plates, proofing systems, and related equipment and chemicals.		
	Systems for electronic uses including connectors, photo resists, conductive compositions, and magnetic products.		
	Clinical, biomedical, and special purpose analytical instruments.		
282	Polymer Products: Acetal, acrylic, fluoropolymer, ionomer, nylon, polyester, and polyolefin resins for molding and extrusion.	1426	1241
282	Chlorosulfonated polyethylene, acrylic, hydrocarbon, fluoropolymer, neoprene, polyester, and urethane synthetic rubbers for industrial and automotive applications.	+528	463
286	Organic isocyanates for use in foam and coatings.		
	Chemicals for processing natural and synthetic rubbers.		
282	Acrylic, ethylene-vinyl acetate, nylon, and polyvinyl alcohol polymers and copolymers for adhesives and coatings.		
30	Cellulosic, fluoropolymer, polyester, polyimide, polyolefin shrinkable, and polyvinyl fluoride films for packaging, industrial, and construction uses.		
30	Fabricated plastics including acrylic sheeting, filaments, fluoropolymer heat exchangers, light guides, microfoam sheeting, netting, pipe systems, polyimide and aramid parts and shapes, safety glass sheeting, strapping and water purification permeators.		
	Methacrylate monomers.		
282	Textile Fibers: Nylon, aramid, polyester, spandex, and fluoropolymer yarns, polyester fiberfill, and acrylic, nylon, and polyester staple for textile, carpet, and industrial uses.	2873	2580
30	Polyester, polyethylene, and polypropylene fibrous spunbonded sheet structures.		
	Polyester and cellulosic fibrous spunlaced sheet structures.		

SOURCE: DuPont Annual Report.

Note: As of 1979, DuPont had combined the seven categories listed above into three groups for financial reporting purposes, even though the company had kept the actual operations of these groups separate.



Table 12

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Charles
River
Associates

ROHM & HAAS PRODUCTS

**POLYMERS, RESINS
AND MONOMERS**

- 282 Rhoplex and Acrysol acrylic emulsion polymers and copolymers for
 -Latex paints
 -Factory-applied finishes
 -Printing inks
 -Saturants, adhesives and finishes for textile and paper products
 -Floor polishes, cement modifiers, caulks and adhesives
- 282 Primal acrylic and Hydrholac nitrocellulose binders for leather finishes
- 282 Acryloid acrylic resins and solution polymers for automotive and industrial finishes
- 284 Tamol dispersants and Triton surfactants
- 282 Acrylate and methacrylate monomers sold as chemical intermediates

**INDUSTRIAL
CHEMICALS**

- Chemical additives for the petroleum industry
 -Primene antioxidants for fuels
 -Acryloid viscosity-index improvers and pour-point depressants for lubricants
 -Plexol synthetic lubricants
 -Romax oil well drilling aids
- 282 Fluid process chemicals
 -Amberlite ion exchange resins and Ambersorb adsorbents
- Sanitary chemicals
 -Hyamine and Kathon biocides and Triton surfactants
- 2879
284 Specialty chemicals

PLASTICS 282: materials
30: products

- 30 Plexiglas acrylic sheet for signs, glazing, skylights, lighting and general industrial uses
- 282 Plexiglas acrylic molding powder for lighting and automotive lenses and safety glazing
- 282 Acryloid impact modifiers and processing aids and Paraplex and Monoplex plasticizers for polyvinyl chloride
- 30 Tuffak polycarbonate sheet for signs and glazing
- 30 Kydex acrylic/PVC alloy sheet for formed components and wallcovering
- 282 Paraplex P-19 polyester molding resin

**AGRICULTURAL
CHEMICALS**

- Dithane, Karathane, Dikar and Indar fungicides to control diseases on fruit, field and fiber crops
- Pesticides Stam, Stampede, Tok, Kerb, Goal and Blazer selective pre- and post-emergence herbicides to improve crop yield through weed control
- Perthane insecticides and Kelthane miticides for orchard and field crops
- Vacor rodenticide
- 284 Triton spray adjuvants and surfactants
- 2873 Ammonium sulfate—a byproduct of methyl methacrylate manufacture sold for use as fertilizer

Table continued on following page.



Table 12 (Continued)

ROHM & HAAS PRODUCTS

SUMMARY OF 1977 RESULTS OF CONTINUING OPERATIONS BY INDUSTRY SEGMENT

(Refer to page 28 for 1976 results)

	Polymers Resins & Monomers	Plastics	Industrial Chemicals	Agricultural Chemicals	Other Industries	Total
(millions of dollars)						
Sales to customers	\$474.9	\$254.6	\$198.5	\$169.8	\$26.1	\$1,123.9
Operating profit (loss)	48.7	25.2	32.0	20.1	(9.9)	116.1
Interest expense						(36.3)
General corporate expenses						(6.6)
Equity in net earnings (losses) of affiliates	—	—	0.6	1.7	(3.6)	(1.3)
Earnings before income taxes						\$ 71.9
Identifiable assets at 12/31/77	\$428.6	\$198.3	\$129.3	\$122.4	\$57.4	\$ 936.0
Investments in affiliates	2.0	—	4.8	8.0	2.7	17.5
General corporate assets						22.9
Total assets at 12/31/77						\$ 976.4
1977 Depreciation expense	\$ 44.3	\$ 15.0	\$ 7.5	\$ 4.5	\$ 1.7	\$ 73.0
1977 Capital expenditures	28.9	5.3	17.3	7.8	18.3	\$ 77.6

FIVE-YEAR SALES ANALYSIS BY INDUSTRY SEGMENT

	1977	1976	1975	1974	1973
(millions of dollars)					
Polymers, Resins & Monomers	\$ 474.9	\$ 443.6	\$360.8	\$339.1	\$267.0
Plastics	254.6	233.9	173.7	201.5	163.0
Industrial Chemicals	198.5	180.9	160.9	168.7	118.4
Agricultural Chemicals	169.8	130.7	174.8	140.8	92.8
Other Industries	26.1	24.5	18.9	17.4	7.4
Total	\$1,123.9	\$1,013.6	\$889.1	\$867.5	\$648.6

SOURCE: Rohm & Haas Annual Report.

For some of these SIC codes we may want to refine the classification to the 4- or 5-digit level if there appear to be significant distinctions between the various subcategories. In the same way, we may want to aggregate some of the 3-digit codes when they seem to present a similar innovative pattern (for example, SICs 285, 287, 289 and 291 present little innovation). Finally, once data are assembled on the industry and the various companies, we may want to group these companies according to their competitive strategies if a clear pattern emerges.

APPENDIX C
DATA SOURCES

Table C-1. Description of Data Sources

Title	Author or Agency	Type of Data Reported	Level of Aggregation	Years Covered	Additional Details	Type of Dollars	Form and Availability	Explanatory Remarks
Research and Development in Industry; Technical Notes and Detailed Statistical Tables	NSF	1. R&D Expenditures and employment 2. Sales	2 and 3-Digit SIC Codes	Historical trends; detail for current year	1. Total R&D funds, federal and company R&D funds, R&D scientists and engineers, net sales, and total employment by 2-digit SIC code.	Current	Annual report; microfiche	This is the most thorough survey of R&D in the U.S. It includes questionnaire (with definitions and notes on changes) and statistical justification. Data not available for companies with fewer than 1,000 employees. Only manufacturing companies performing R&D are included in this sample.
					2. R&D funds by 2-digit SIC code (and some 3-digit groups) by size of company and by size of R&D program.			
					a. company funds b. funds contracted to outside organizations			
					3. Percent of total and Federal R&D funds and of net sales of all R&D performing companies by size of R&D program, by 2 or 3-digit SIC code.			
					4. Distribution of companies by employment, by 2 or 3 digit SIC code.			
					5. Geographic distribution of funds for total industrial R&D.			
					6. Distribution of R&D costs, by 2 or 3-digit code, by type of cost: wages for scientists and engineers, and for supporting personnel, materials and supplies, other costs.			
					7. FTE of R&D scientists and engineers by 2 or 3-digit SIC code; also by source of R&D funds (company vs. federal).			

Table C-1. (Cont'd)

Title	Author or Agency	Type of Data Reported	Level of Aggregation	Years Covered	Additional Details	Type of Dollars	Form and Availability	Explanatory Remarks
R&D in Industry (continued)					8. Man-years and cost of R&D scientists and engineers by 2-digit SIC code. 9. Cost per R&D scientist or engineer by 2 or 3-digit SIC code, by size of company. 10. Net sales by 2 or 3-digit SIC code, by selected company size group. 11. R&D as percent of net sales by 2 or 3-digit SIC code and by size of company; also by size of R&D program. 12. R&D broken down into basic research, applied research, and development, by 2 or 3-digit SIC code and by company size.			
Chemical and Engineering News; Facts and Figures for R&D Issue		R&D expenditures	1. 2 and 3-digit SIC codes 2. Company (17 included)	Annual; Historical data for 10 years, projected data for 1 year				Compilation of NSF data
Chemical Industry Notes	Predicasts, Inc.	1. Abstracts of reports	Varies by article	Revised monthly since 1974	Bibliographic service		Computer on-line from 1972 and publication through DIALOG	Collected from 80 periodicals

Table C-1. (Cont'd)

Title	Author or Agency	Type of Data Reported	Level of Aggregation	Years Covered	Additional Details	Type of Dollars	Form and Availability	Explanatory Remarks
Census of Manufactures Survey of Manufactures	Dept. of Commerce	1. Sales 2. Production 3. Employment a. Production b. All	5-Digit SIC code by: 1. U.S. 2. State 3. County 4. Places of 2500 or more inhabitants	1. Census every 5 years since 1947 2. Survey annually	Data includes: value added by manufacture, cost of materials, value of shipments, new capital expenditures		Publication on computer tape, microfiche	1. Census was conducted sporadically since 1810. 2. Approximately 70,000 establishments included in annual survey. 3. Includes all multi-establishment companies and the larger single-establishment companies.
Oil Paint and Drug Chemical Buyers Directory	Chemical Marketing Reporter	1. Chemical 2. Producer	By chemical	Annual report			Publication	Can compare yearly reports to determine new chemical entities.
Producer Prices and Price Indexes	Bureau of Labor Statistics	1. Prices 2. Producer price indexes	5-digit SIC code	Monthly report		Constant	Publication	
Chemical in Commerce Information System	EPA	1. Chemical producers 2. Annual production	1. By EPA region and nation 2. By chemical	Annual update	Over 47,000 chemicals		On line.	
TSCA Chemical Substance Inventory	EPA-Industry Assistance Office	1. Chemicals 2. Producers 3. Importers	By CAS registry number		1. Approximately 44,000 chemicals. 2. General range of production volume by chemical, by company.		Computer print-out, microfiche, tape	Initial inventory until June 1, 1979. Revised inventory June 1, 1979 to December 31, 1979. Contact: 800-424-9065.

Table C-1. (Cont'd)

Title	Author or Agency	Type of Data Reported	Level of Aggregation	Years Covered	Additional Details	Type of Dollars	Form and Availability	Explanatory Remarks
The Kline Guide to the Chemical Industry	Charles H. Kline & Co., Inc.	1. Production	1. 3-digit SIC codes	Current annual and historical data; forecasts for shipments	1. Sales for 465 companies; sales and profitability for publicly held companies	Constant	Publication	
		2. Sales	2. By chemical		2. Production, sales, and average prices by chemical			
		3. Employment	3. 465 leading U.S. chemical companies		3. Number of employees by 3-digit SIC code			
		4. Capital expenditures						
		5. Average prices						
Directory of Chemical Producers	SRI	1. Chemicals	1. Chemical	Revised annually	1. Companies with list of their products by specific site of manufacture		Publication	10,000 chemicals, 1500 companies
		2. Producers	2. Company		2. Chemicals and end-use groupings of chemicals with list of producers by plant location			
Data Resources, Inc.	DRI	1. Capacity by company 2. Discussion of market trends 3. Production and price history	By chemical	Annual since 1966	Forecast demand and price for 90 major chemical	Current	Computer on-line	Collected from other public sources and SRI

Table C-1. (cont'd)

Title	Author or Agency	Type of Data Reported	Level of Aggregation	Years Covered	Additional Details	Type of Dollars	Form and Availability	Explanatory Remarks
Synthetic Organic Chemicals	ITC	1. Production 2. Sales 3. Price data 4. Manufacturer	By chemical	Annual since 1973	Data for synthetic organic chemicals.	Current	Publication	Financial statistics exclude chemicals for which there are fewer than three producers.
Process Economics Program (PEP) Reports	SRI	1. Capital & Production cost 2. Technical aspects of production 3. Producers 4. Representative patents 5. Costs by process 6. Patents by process	By chemical or chemical group	Continuous coverage. Periodically updated.	Data for major chemicals, roughly the largest 150.	Constant	Publication, available through subscription, available at EPA	Includes process economics as opposed to supply and demand statistics.

Table C-1. (Cont'd)

Title	Author or Agency	Type of Data Reported	Level of Aggregation	Years Covered	Additional Details	Type of Dollars	Form and Availability	Explanatory Remarks
Chemical Economic Handbook	SRI	1. Capacity by company and by process 2. Consumption history and projection 3. Sales	By chemical or chemical groups	Continuous program updated periodically	Characterizes supply and demand markets for major chemicals; includes more chemicals than periodically PEP report.	Current	Publication available through subscription available at EPA	Most complete information available on supply/demand of chemicals covered.
Disclosure/SEC Reports	Disclosure, Inc., SEC	1. Financial statements 2. Other business information	Company	Annual	1. Financial statements include Consolidated Income Statements, Balance Sheets, etc. 2. Business information includes principal products and services, principal markets, estimated cost of research, # of employees importance of patents, effects of compliance with environmental regulation, etc.	Current	Computer data base from 1979; publication from 1934	Not all business information is always included. This report is filed by publicly-held companies with over \$1 million gross assets and over 500 shareholders.
10-K		1. Financial statements 2. Other business information	Company	Quarterly (unaudited)	1. Financial statements include Income statement and Balance Sheet.	Current	Computer data base from 1979	This report is filed by publicly-held companies with over \$1 million gross assets and over 500 shareholders.
10-Q		1. Financial statements	Company	Annual		Current	Computer data base from 1979	This report is filed by publicly-held companies with over \$1 million gross assets and over 500 shareholders.
8-K		1. Company, organization and changes	Company	Annual		Current	Computer data base from 1979	This report is filed by publicly-held companies with over \$1 million gross assets and over 500 shareholders.

Table C-1. (Cont'd)

Title	Author or Agency	Type of Data Reported	Level of Aggregation	Years Covered	Additional Details	Type of Dollars	Form and Availability	Explanatory Remarks
Dunn & Bradstreet	Dun & Bradstreet		1. 4-digit SIC code 2. Company	Annual			Computer data base	This is not an exhaustive report of all companies.
Corporate Compustat	Standard & Poor		Company	Annual, some quarterly			Computer on-line	
Chemical Week		Financial statistics	Companies aggregated by 3 or 4-digit SIC chemical group	Annual			Periodical	Various types of data reported throughout year.
Chemical Marketing Reporter		1. Market environment 2. Prices	By chemical	1. Weekly 2. Monthly	1. Weekly reports contain market environment information and list prices. 2. Monthly reports contain ITC information (sales or production volume) for selected chemicals		Periodical	

Table C-2

Assessment of Data from Available Public Sources*

Production Function Variables (Tentative List)	Level of Aggregation		
	4-Digit SIC**	Company	Industry
New Chemical Entities	none	7, 8 (both are limited)	7, 8 (both are limited)
New Chemical Sales	none	none	none
Chemical Patents	none	1	1
Process Patents	none	1	1
Total Sales	2	4, 5	2, 4, 5
Profits/Value Added	2	4, 5	2, 4, 5
Engineers and Scientists	none	5 (sometimes)	5, 6
Research and Development Dollars	none	5 (usually)	5, 6
Capital Investment	2	4, 5	2, 4, 5
Capacity Utilization	none	none	none
Market Concentration	2 (to some degree)	3, 4, 5	3, 4, 5
Strategic Grouping	2 (to some degree) 3 (with some work)	3, 4, 5	3, 4, 5

* Cell entries refer to the following sources:

1) IFI/Plenum Patent Service; 2) Census of Manufacturers; 3) Dun and Bradstreet; 4) 10-K Reports; 5) Company Annual Reports; 6) NSF Survey of Research and Development; 7) Buyers' Guides; 8) Marketing Development New Product Directory.

See Notes (to follow) for discussion of sources.

** For information to be applicable here, it must be compatible with the Census of Manufacturer's definition.

Table C-2 (Continued)

Assessment of Data from Available Public Sources

Notes to Table C-2

Primary Data Sources

1. IFI/Plenum Data Sources -- this source provides chemical patent information dating back to 1950. Since 1972, they have distinguished the type of chemical patent (product, process or machinery). This information can be accessed selectively by company, but not by 4-digit SIC code. Even if it could be assigned to 4-digit SIC groups, the data would not be compatible with the Census of Manufacturers' aggregation.
2. Census of Manufacturers -- this census provides sales, production volume, value added, capital investment, number of employees, number of establishments and several other pieces of information for each 4-digit SIC group. Most of the data are collected annually at the level of each business establishment whose primary product is that SIC group. The data pertaining to a corporation will therefore be reported at the level of each of its individual establishments (which are often in different 4-digit SIC groups). Furthermore, data pertaining to a specific product group are not presented in the display since the report pertains to establishments and aggregates all the various products manufactured at an establishment under the 4-digit SIC of the primary product group. Selectivity ratios and concentration ratios are provided by the Census to indicate (1) the portion of any 4-digit SIC group data which is actually made up of the 4-digit SIC product, and (2) how much of that product is actually reported within the group.

The selectivity and concentration ratios for the chemical industry are not consistently high and are in the range of .7 to .90. This reflects the integrated nature of the industry and it also suggests the incompatibility of Census of Manufacturers data with any other data source which would aggregate by product group.

The five year Census of Manufacturers also provides a breakdown of the 4-digit SIC level information according to some criteria of scale. A size distribution is provided and all of the information is broken down into two scale groups.

3. Dunn and Bradstreet Data -- This is a listing of business establishments by 4-digit SIC code which includes such information as company name, sales and employees at the establishment level, and total employees at the company level. It is particularly useful as a complete list of all business establishments producing chemicals as their primary product.
4. 10-K Reports -- the Securities and Exchange Commission requires that these forms be filed annually by all publicly owned companies with gross assets of over one million dollars and with over 500 shareholders. The information provided includes sales, capital expenditures and assets for a given year. These reports are available in their present form dating back to 1966 and in some form since 1934. Recent information (since 1979) is available on-line from a data handling service known as Disclosure. Clearly this information excludes small and privately owned companies.
5. Annual Reports -- these are available for most publicly owned companies and usually include a 10-K report and such additional information as dollars spent in research and development, sales in various product areas, and technical and scientist labor.
6. "Research and Development in Industry" by the National Science Foundation -- this survey provides various statistics on engineers and scientists employed and R & D dollars spent in the various sectors of the U.S. economy. Unfortunately for our purposes, the relevant chemical information is aggregated into only two groups: SIC 281-282 and SIC 284-289. It is therefore a useful measure of overall industry trends but provides no data for analysis at either the 4-digit level or the company level of aggregation.
7. Annual Chemical Buyers Guides -- these lists of commercially available chemicals available from Chemical Week (a McGraw-Hill publication) or Chemical Marketing Reporter. It is possible to compare different volumes of the reports to identify new chemical offerings by a given company in a specific year. Data obtained in this manner unfortunately would omit chemicals which have not been marketed, such as specialty chemicals produced for a specific buyer or for internal use. It also lists chemicals by the distributor, an entity which may differ from the innovator.
8. New Chemical Directory by Marketing Development Inc. -- Marketing Development consults the annual reports of several hundred chemical companies to develop their list of new chemicals. The data base only dates back to 1976 and it omits those specialty products which are not announced, and all products produced by those small or private chemical companies which were omitted from the survey.

APPENDIX D

REVIEW OF STUDIES OF 1962 DRUG AMENDMENTS

Author: Baily, Martin Neil

Title: "Research and Development Costs and Returns: The U.S. Pharmaceutical Industry," Journal of Political Economy, January-February 1972, pp. 70-85.

Affiliation: Massachusetts Institute of Technology

Funding: Ford Foundation and Canada Council

Publisher: Journal of Political Economy

Type of Study:

1. Baily used econometric analysis to test the relation between innovative output and the 1962 drug amendments.
2. He also computed industrywide rates of return on drug R&D before the 1962 amendments.

1. R&D Expenditures and Innovative Output:

Baily used an econometric approach to model the introduction of new drugs in the U.S. pharmaceutical industry from 1954 to 1969. He related new drug introduction per dollar of R&D to two independent variables: a dummy representing the 1962 amendments and a measure of the depletion of research opportunities.

$$N/E = f(D, P, \mu)$$

where:

N = number of new drugs introduced by U.S. firms, as measured by P. deHaen Inc.;

E = R&D expenditures for the drug industry, measured by the average for a three-year period starting six years before the introduction of the drugs;.

D = dummy variable for the 1962 amendments, set at zero through 1961 and unity thereafter;.

P = a measure of the depletion of research opportunities, measured by the average of new drug introductions during a seven-year period starting thirteen years before the introduction of the newer drugs; and

μ = a disturbance term.



He finds that the two variables contribute to explain the rate of introduction of new drugs. His R^2 is .947 and the other terms are as follows:

<u>Variable</u>	<u>Coefficient</u>	<u>Standard Error</u>
Constant	4.708	0.295
1962 amendments	-1.337	0.218
Research opportunities	-0.03854	0.0104

2. Expected Financial Returns to Pharmaceutical R&D:

Again, Baily used an econometric approach to model the dollar returns to pharmaceutical R&D from 1954 to 1963 for six individual firms. He related dollar profits adjusted for market size to two independent variables. The first variable is the number of new drugs introduced by the firm during the year. The second variable is a company-specific geometric function for the time distribution of returns.

Baily tested for differences in dollar returns for pre- and post-1961, even though he had data for only two years following 1961. "No equation showed a significant difference" (page 81).

Then Baily computed industrywide rates of return on drug R&D. He used an industrywide time series of average cost per new drug. Next, he developed a time series of average profits for the six firms mentioned above. Finally, he took the internal rate of return. He concluded that pretax earnings "showed a distinct and steady pattern starting around 35 percent in 1954 and falling evenly to around 25 percent in 1961" (page 82).

Conclusions:

Four major conclusions derive from Baily's paper:

1. "It does not require econometrics to see [...] that 224 new drugs were introduced from 1954 to 1961 and 86.5 from 1962 to 1969 [even though] much more was spent on R&D" (page 83). A dummy variable representing the 1962 amendments was significant in explaining the rate of introduction of new drugs.
2. But Baily found that a variable measuring the depletion of research opportunities caused by prior drug development (irrespective of the 1962 amendments) was also significant.

Author: Peltzman, Sam

Title: Regulation of Pharmaceutical Innovation, The 1962 Amendments
(Washington, D.C.: American Enterprise Institute for
Public Policy Research, 1974).

Affiliation: Professor of Business Economics, University of Chicago
Graduate School of Business

Funding: Center for Policy Study, University of Chicago

Publisher: American Enterprise Institute

Type of Study:

Peltzman analyzes the effect of the 1962 drug amendments on:

1. The flow of new drug innovations
2. The net costs and benefits to consumers
3. The costs and benefits of unsafe and highly successful drugs to consumers
4. The wealth of drug producers

1. The Flow of New Drug Innovations

In his discussion on the decline of drug introductions since the 1962 amendments, Peltzman presents his drug innovation model based on Schmookler's assumptions that the supply of innovations is a response to the demand for innovation. Using Schnee's estimate that most of the pre-1962 NCE introductions occurred one to three years after the beginning of the development process, Peltzman presents his evidence on the effect of market conditions on future innovations (Figure 1). Even with a slight lagged drug market growth rate of 5.5 percent after 1962, compared with a 5.1 percent pre-1962 counterpart, the author observes a significant reduction in NCE introductions.¹ Reporting on sales data, Peltzman shows that "important new NCE" sales as a percent of all drug prescriptions fell from 1.58 percent in 1960-1962 to 0.57 percent in

¹Peltzman disputes FDA statements that the number of "truly important, significant and unique therapeutic entities ... has remained relatively stable" from 1950 to 1972. In his mind, all new effective drugs are important, the incremental as well as the major ones (pages 85 to 87).

in 1964-1969. And finally, Peltzman presents evidence supported by Schnee and Wardell suggesting that the new drug development time period increased by an average of two years after 1962. Peltzman suggests that the resultant reduction in the flow of NCE's after 1962 is attributable to the 1962 amendments.

2. The Net Costs and Benefits to Consumers

Peltzman derives estimates of the net consumer benefits of the 1962 amendments employing a consumer surplus approach utilizing physician-patient prescription data on drug submarkets (therapeutic categories) for a period covering the 1962 amendments. Peltzman finds a decline in drug output and sales along with stable prices before and after 1962 in his following estimates:

Average Market Share and Relative Price for NCE's in Year After Introduction

	<u>Average Number of Categories with NCE's</u>	<u>Average Per- cent of NCE Prescriptions</u>	<u>Price Ratio of NCE to Other Drugs in Category</u>
1956-7	11.0	13.2	1.223
1960-2	10.3	10.7	1.263
1964-9	5.4	6.4	1.165 (p.34)

Peltzman estimates the net loss to consumers resulting from the decline in drug innovation brought by the amendments at a net annual loss of \$400 million in consumer benefits assuming an indefinitely long market life, and a \$330 million net annual loss in consumer benefits assuming a 15-year average market life (p. 38 and Table A-2 of the Appendix).

Checking on the introduction of ineffective drugs, Peltzman compares the drug use patterns of physician-patients with evaluations by drug experts. Peltzman employs the prescription pattern data and drug assessments of hospitals, state public assistance program formularies and the American Medical Association, estimating a consumer gain of under \$100 million from the reduced waste on purchases of ineffective new drugs after 1962.

Lastly, Peltzman calculates the effect of innovation on drug prices assuming that NCE's with potential market shares are blocked from entry into the market; this barrier to entry decreases market competition, thus allowing prescription price increases. Peltzman estimates the cost to consumers to be about \$50 million annually (based on 1970 sales

data). Summarizing the annual gains and losses Peltzman derives a net loss of \$250-350 million in reduced net benefits, or about 7 percent of total drug expenditures by the consumer due to the 1962 amendments.

3. The Costs and Benefits of Unsafe and Highly Successful Drugs to Consumers

Peltzman calculates the costs and benefits of unusually unsafe and highly successful drugs left untouched by the previous analysis. He looks at the measurable health effects of the harmful drugs Chloraphenicol and Thalidomide introduced prior to 1962. Assuming that two such pharmaceutical tragedies occurred each decade without the 1962 amendments, the estimated benefits incurred under the amendments would be under \$100 million annually (p. 56). Peltzman then looks at the measurable effects of three past highly successful drug innovations; tuberculosis therapy, tranquilizers and polio vaccines. He estimates the net benefits of the innovations 10 years after introduction as well as the cost of a 2-year delay in the introduction in the following table:

	<u>TB</u>	<u>Tranquilizers</u>	<u>Polio Vaccines</u>
<u>Net Benefits</u>	\$12 billion	\$8 billion	\$900 million
<u>Cost of 2-year delay</u>	\$2 billion (p.62)	\$1.4 billion (p.66)	\$150 million (p.68)

Peltzman warns of the difficulties in assigning single values to the costs and benefits of past innovations as well as estimating prospective values. He then qualifies himself by assuming that future innovations will repeat the past in the number of people affected. Peltzman concludes that "[t]he 1962 amendments assume implicitly that it is worth sacrificing some potential return from an innovation in order to gain reduced risk." Yet Peltzman's "estimates suggest that if any trade would be profitable, it would be more risk for more return." (p. 72).

4. The Wealth of Drug Producers

Peltzman estimates the rate of return and the rate of growth for a representative group of drug producers before and after the 1962 amendments. Referring to Table 12 (p. 77) Peltzman compares the annual rate of return of drug stocks with Standard & Poor's Industrials ("the market"), indicating little difference with the introduction of the amendments. Comparing the rate of growth of drug sales with the Gross National Product



similarly yields higher drug sales before and after 1962. Peltzman concludes that the resulting gains of reduced competition allowing greater protection of the market position of established drugs has offset the impact of reduced returns to each innovation with the cost and demand effects of the amendments. Analyzing the variability of the returns on drug stocks with the Standard & Poor's Industrials before and after 1962 indicates the reduced volatility of drug stocks. Peltzman concludes that the net benefits of the greater stability of wealth of drug companies with the amendments yields a highly tentative estimate of \$200 million annually (p. 79).

Conclusion:

Peltzman's study presents three major conclusions regarding the impact of the 1962 amendments:

1. A significant decline in number and an increased development period for New Chemical Entities.
2. A net cost and potential loss of future valuable innovations to consumers.
3. As a group drug producers have neither been aided nor hindered. The gains of reduced competition have been offset by the increased costs of innovation. However, the reduced variability of returns to drug companies relative to other stocks since 1962 has benefited drug producers with a greater stability of wealth.



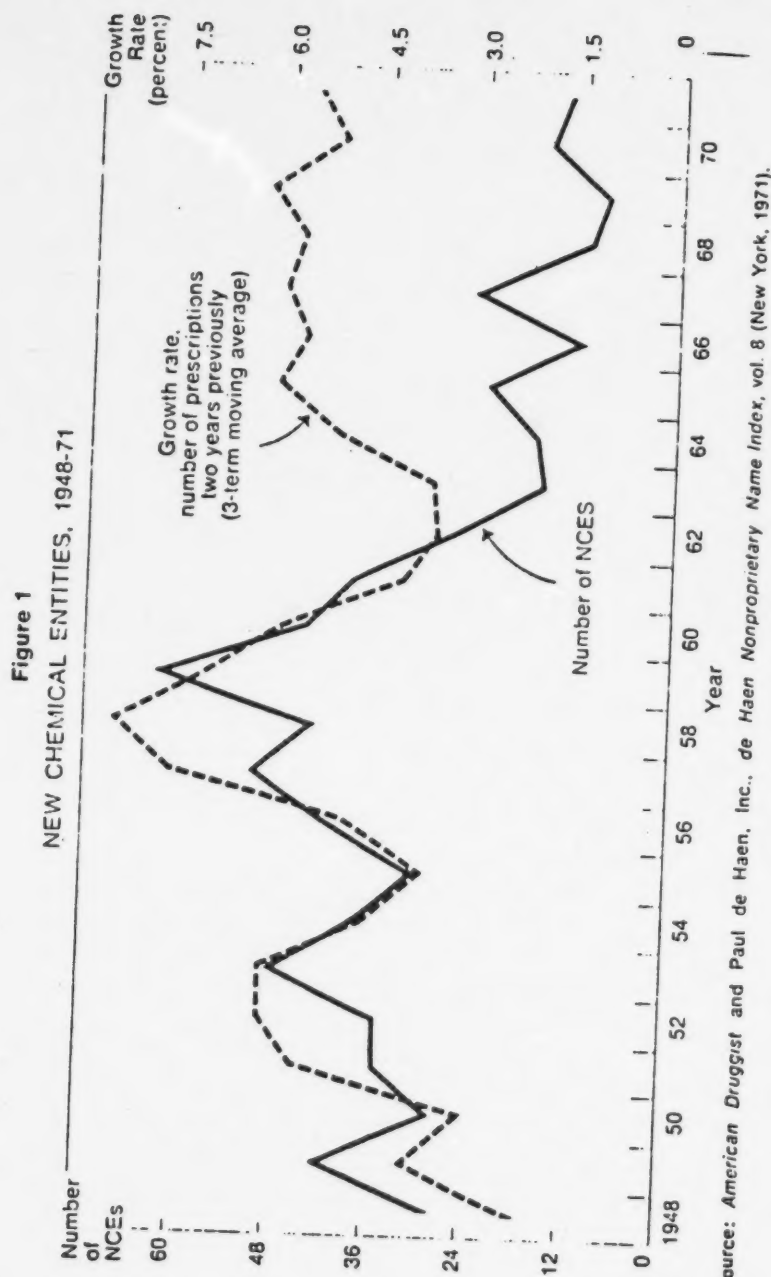


Table 12
RATES OF RETURN FOR DRUG STOCKS AND STANDARD
AND POOR'S INDUSTRIALS, AND ASSOCIATED DATA
(selected periods)

Datum	Period	
	1949-61	1962-71
Average compound annual rate of return:		
1. Drug stocks	23.0%	12.3%
2. Standard & Poor's Industrials	17.7	7.7
3. Difference (line 1 - line 2)	5.3	4.6
Average compound annual rate of growth (constant dollars):		
4. Drug sales	5.6	6.0
5. Gross national product	3.2	3.9
6. Difference (line 4 - line 5)	2.4	2.1
Difference between return in one year on drug stocks and Standard and Poor's Industrials:		
7. Highest difference in period	33.4	18.3
8. Lowest difference in period	-11.9	-7.5
9. Range (line 7 - line 8)	45.3	25.8

Note: Line 1 is the average annual wealth change (that is, capital gains plus dividends) as a percent of wealth at the start of each year for an investor concentrating his wealth on drug stocks. The investor is assumed to sell his holdings each year and reinvest the proceeds along with dividends equally among all drug stocks used in the calculations. These drug stocks are listed in the note to appendix Table A-3. Tax and transactions costs are not included.

Line 2 is the average annual percentage wealth change for an investor who buys a "share" of Standard and Poor's Industrial Stock Price Index and reinvests all dividends.

Lines 4 and 5 are the average compound annual growth in drug sales and gross national product, measured in constant 1958 dollars.

The data on lines 7, 8 and 9 are obtained by subtracting in each year the percentage wealth change for the investor in Standard and Poor's Industrials from that for an investor in five drug stocks, where data are available for each year 1949-71 (these are Abbott, American Home Products, Merck, Pfizer, and Smith, Kline and French). Line 7 shows the highest such difference in each period and line 8 the lowest.

Source: See Appendix, Table A-3.

Author: Schwartzman, David

Title: The Expected Return from Pharmaceutical Research: Sources of New Drugs and the Profitability of R&D Investment (Washington, D.C.: American Enterprise Institute for Public Policy Research, 1975)

Affiliation: Professor of Economics, New School for Social Research

Funding:

Publisher: American Enterprise Institute

Type of Study:

For pre- and post-1962 drug amendments, Schwartzman analyzes:

1. The relation between R&D expenditures and innovative output; and
2. The expected rate of return on pharmaceutical R&D.

1. R&D Expenditures and Innovative Output:

Schwartzman derives estimates of the increase in the current R&D costs per new chemical entity. His calculations indicate that the unit cost per new drug has increased from \$1.3 million in 1960 (page 42) to \$24.4 million in 1973 (page 28). The author also reports on a study by M. N. Baily, who estimated through an econometric analysis that the cost per new drug had more than doubled following the 1962 amendments. As seen in Table 4 from the text, Baily's cost estimates differ markedly from those of Schwartzman: the two used different methods and had different objectives. Baily aimed at estimating the extra costs directly attributable to the 1962 amendments, while Schwartzman was reporting on overall cost increases.

2. Expected Returns to R&D:

Schwartzman performs detailed calculations to estimate rates of return to drug innovation. He uses industrywide figures and averages from various sources, documenting or explaining all his numbers. He derived the following estimates for internal rates of return:

Expected* Rates of Return to Pharmaceutical R&D

<u>Period</u>	<u>Post Tax Rate of Return</u>	<u>Source in the Text (Page)</u>
1960	11.4 percent	43
1967	negative	45
1973	3.3 percent	34

Schwartzman discusses the various factors that could modify his estimates: variations in gross margin, expected commercial life and overall market growth. But he concludes to the reasonableness of his estimates.

In a chapter on public policy issues, Schwartzman states his conclusions very carefully. He cites Baily and Peltzman for the specific effects of the 1962 amendments; reports that innovative output, and financial return to innovation have decreased; but avoids making any conclusive statements as to the possible contributing factors.

Other Findings:

1. Schwartzman presents his evidence and that of J. Schnee and M. Seife estimating the drug industry's larger share of discoveries.
2. Schwartzman observes a positive relationship between R&D and the size of the firm with the number of new chemical entities increasing more than laboratory employment. He also mentions studies by Baily and Peltzman.

*The author uses the term "expected" for all three of these rates of return. It seems to mean "average" and "prospective."

Table 4
COMPARISON OF ANNUAL EXPENDITURE REQUIRED TO
DEVELOP A CONSTANT NUMBER OF NEW DRUGS (N),
PRE-1962 AND POST-1962
(millions of 1957-1959 dollars)

N	Before the 1962 Regulations Change		After the 1962 Regulations Change	
	Total	Cost per NCE	Total	Cost per NCE
5	12.35	2.47	29.09	5.82
10	29.94	2.99	70.55	7.06
15	54.45	3.63	128.3	8.55
20	88.03	4.40	207.4	10.37
25	133.4	5.34	314.4	12.58
30	194.1	6.47	457.4	15.25

Source: Martin Neil Bailey, "Research and Development Costs and Returns: The U.S. Pharmaceutical Industry," *Journal of Political Economy*, vol. 80 (January/February 1972), p. 78.

The 1962 Drug Amendments and R&D Costs

It is also disturbing that public policy changes have increased the cost of pharmaceutical R&D. Several studies indicate that the 1962 drug amendments contributed markedly to this effect. I have reported my own estimate that the current-dollar R&D cost of a new chemical entity was \$1.3 million in 1960 as against \$24.4 million in 1973. The thirteen-year increase in prices of goods and services used by research laboratories was about 68 percent.² Thus, the increase in costs of R&D for reasons other than price increases is 1015 percent. Not all of this increase can be attributed to greater severity in the regulatory requirements. Some of it comes from the increased difficulty of discovering and developing new drugs in therapeutic fields where many good drugs already exist. Some results from the fact that new effort and resources are currently being devoted to the discovery of drugs for diseases about which relatively little is known and which are intrinsically difficult to deal with—diseases such as arthritis and diseases of the cardiovascular system. Dr. Sarett has estimated that the development cost of a new drug (as opposed to discovery research) rose from \$1.2 million in 1962 to \$11.5 million in 1973.³

Developmental research only begins when the laboratory has decided (on the basis of animal tests) that a compound is sufficiently promising to warrant clinical tests on humans. The estimate made here of the share of total R&D costs devoted to development—an estimate which is based on industry sources—is 50 percent. The closeness of Dr. Sarett's estimate of developmental costs per NCE in 1972 to my own provides some indication of the validity of these estimates and supports the conclusion that the costs have increased greatly. Studies by Bailly and by Peltzman provide estimates of the effect of increased regulatory stringency on R&D costs. Bailly estimated that the drug amendments increased the cost of R&D required for a given number of new chemical entities by 136 percent.⁴ Peltzman estimated that they doubled the cost.⁵

As a consequence, the industry has not been able to maintain its pre-1962 rate of innovation, despite a large increase in spending. The cost of producing innovations has risen faster than overall spending. Measured by its output, pharmaceutical R&D has become a declining industry. Moreover, the increase in costs has produced a sharp reduction in the expected rate of return from investment in R&D. If this expected rate declines still further, investment in R&D will decline and the rate of drug innovation will fall even more than it has. It should be emphasized that the rate of innovation has fallen, even though expenditures for R&D continue to increase in constant as well as in current dollars. I am suggesting that the increase in R&D expenditures would have been larger had it not been for the increased restrictiveness of Food and Drug Administration regulatory policy. There is no doubt that the discovery component of R&D spending would have been larger.

APPENDIX E
DERIVATION OF R+D DEMAND EQUATION

Appendix E
Derivation of the R+D Equation*

The equation describing the determinants of R+D is derived from relations that govern the effects of R+D expenditures on costs. As is implicit in the production function, we assume that the average costs to the firm vary directly with the stock of knowledge, i.e., that a measure of knowledge exists such that average costs, C , are given by

$$C = \frac{c(w)}{K}$$

where

$c(w)$ = average variable (non-R+D) costs,
 w = factor prices, and
 K = the stock of knowledge.

Increments to knowledge, $\dot{K}$ are produced by R+D

$$\dot{K} = \bar{R}^\alpha$$

where

$\bar{R}$ = stock of R+D produced by R+D expenditures, and
 α = a constant elasticity.

The stock of knowledge at time t is the sum of all prior increments to knowledge discounted to reflect their loss in productive value over time.

Thus,

$$K_t = \int_{-\infty}^t \dot{K}_s e^{-\lambda(t-s)} ds$$

*This derivation is due to Mark Scharkerman.

where λ is the rate of obsolescence and t and s are time subscripts.

The above relations can be used to find the marginal cost savings of research expenditures. First, by the chain rule,

$$\frac{d \ln C}{d \ln R} = \frac{d \ln C}{d \ln K} \cdot \frac{d \ln K}{d \ln \dot{K}} \cdot \frac{d \ln \dot{K}}{d \ln R},$$

where R represents R+D expenditures. Since

$$\frac{d \ln C}{d \ln K} = -1,$$

$$\frac{d \ln K}{d \ln \dot{K}} = \frac{\dot{K}}{K},$$

and

$$\frac{d \ln \dot{K}}{d \ln R} = \alpha$$

then

$$\frac{d \ln C}{d \ln R} = -\alpha \frac{\dot{K}}{K}.$$

This expression can be transformed into the marginal cost savings of research expenditures as follows:

$$\frac{d \ln C}{d \ln R} = \frac{dC}{dR} \cdot \frac{R}{C}$$

and thus

$$\frac{dC}{dR} = \frac{d \ln C}{d \ln R} \cdot \frac{C}{R} = -\alpha \frac{\dot{K}}{K} \cdot \frac{C}{R}.$$

The value dC/dR is the marginal cost of research at the margin or the decrease in costs that are obtained by an increase in R+D expenditures.

The expected benefits to R+D expenditures at time t are

$$B_t = - \frac{dC}{dR} Q_t e^{-\delta t} = - \frac{dC}{dR} Q_0 e^{(g-\delta)t} .$$

where

Q_t = production rate at time t ,

δ = rate of decline in the value of benefits due to competitive forces, and

g = expected growth rate of production.

Thus

$$B_t = \alpha k \frac{C_t}{R_t} Q_t e^{(g-\delta)t} .$$

Under the assumption that a firm will spend on R+D up to the point at which the marginal dollar yields a dollar in the present value of the benefits,

$$1 = \int_{\theta}^{\infty} B_t e^{-rt} dt$$

where

r = discount rate and

θ = lag between R+D expenditures and the generation of benefits.

Thus

$$1 = \int_{\theta}^{\infty} \alpha k \frac{C_0}{R_0} Q_0 e^{(g-r-\delta)t} dt$$

which (if $r + \delta > g$) can be integrated to yield

$$1 = \alpha k \frac{C_0 Q_0}{R_0^*} \frac{e^{(g-r-\delta)\theta}}{r + \delta - g}$$

where R_0^* is the optimal level of R+D expenditures.

Now we solve for R_0^* and take the log of the result to get

$$\ln R_0^* = \ln \alpha k + \ln C_0 Q_0 \frac{e^{(g-r-\delta)\theta}}{r + \delta - g}$$

or

$$\ln R_0^* = a + \ln C_0 Q_0 - \ln(r + \delta - g)$$

where

$$a = \ln \alpha k + (g-r-\delta)\theta$$

By the first order Taylor's expansion around $g = 0$,

$$\ln(r + \delta - g) = \ln(r + \delta) - \frac{1}{r + \delta} g$$

Substituting,

$$\ln R_0^* = a' + bg + \ln C_0 Q_0$$

where a' and b are constants.

Let P_0 be the price of output. Then

$$P_0 = C_0 + Z$$

where Z is the payment to R+D inputs equal to the currently accruing quasi-rents. If we assume that Z is equal to a constant proportion of R+D costs, ϕ , then

$$P_0 = C_0 (1 + \phi)$$

where $\phi = Z/C_0$. Then

$$\ln P_0 = \ln C_0 + \ln(1 + \phi)$$

and

$$\ln C_0 = \ln P_0 - \ln(1 - \phi)$$

Substituting in the R+D equation gives

$$\ln R_0^* = a'' + bg + \ln P_0 Q_0$$

where g is the expected rate of growth of production and $P_0 Q_0$ is current sales.

The above equation represents the desired rate of R+D expenditures in a static equilibrium. We introduce a partial adjustment model as follows:

$$\ln R_t - \ln R_{t-1} = \gamma (\ln R_t^* - \ln R_{t-1})$$

where γ is a constant adjustment rate. The resulting equation for R+D demand is

$$\begin{aligned} \ln R_t &= (1 - \gamma) \ln R_{t-1} + \gamma \ln R_t^* \\ &= (1 - \gamma) \ln R_{t-1} + \gamma a'' + \gamma bg + \gamma \ln P_t Q_t \end{aligned}$$

or

$$\ln R_t = \beta_0 + \beta_1 \ln R_{t-1} + \beta_2 g + \beta_3 \ln P_t Q_t$$

where the β_i are constants as follows:

$$\begin{aligned} \beta_0 &= \gamma a'' = \gamma [a' - \ln(1 - \phi)] \\ &= \gamma [\ln ak + (-r - \delta)\theta - \ln(r + \delta) - \ln(1 - \phi)] \end{aligned}$$

$$\beta_1 = 1 - \gamma$$

$$\beta_2 = \gamma b = \gamma \left(\frac{1}{r + \delta} + \theta \right)$$

$$\beta_3 = \gamma$$

The average lag between R+D expenditures and the returns to R+D is*

$$L = \frac{1 - \gamma}{\gamma} + \theta .$$

An alternate model with the adjustment equation in terms of R+D intensity (R+D as a percent of sales) is expressed as follows:

$$\ln R_t - \ln P_t Q_t = \beta_0 + \beta_4 (\ln R_{t-1} - \ln P_{t-1} Q_{t-1}) + \beta_2 g .$$

*It is well known that the specification associated with partial adjustment models is identical to the problem of estimating a Koyck geometric lag of the form

$$y_t = \alpha + \beta \sum_{i=0}^{\infty} w^i x_{t-i} + \epsilon_t$$

where the adjustment factor γ is equivalent to the lag factor w . The mean lag is the average lag period weighted by the individual lag coefficients, and it is straightforward to show that this is equal to $(1-\gamma)/\gamma$. In addition, the constant gestation lag θ must be accounted for, yielding the result in the text. See any econometrics text, e.g., Pindyck and Rubinfeld (1976), pp. 213-215.

APPENDIX F
MODELING OF PRODUCT/PROCESS INNOVATION

Modeling of Product/Process Innovation

Let there be two types of knowledge, K_1 and K_2 . Then the joint production function is $f(\dot{K}_1, \dot{K}_2, R) = 0$ where $\dot{K}_1$ is the increment to K_1 , etc., and R is R&D expenditures. Assuming separability between outputs and inputs:

$$(1) \quad g(\dot{K}_1, \dot{K}_2) = h(R)$$

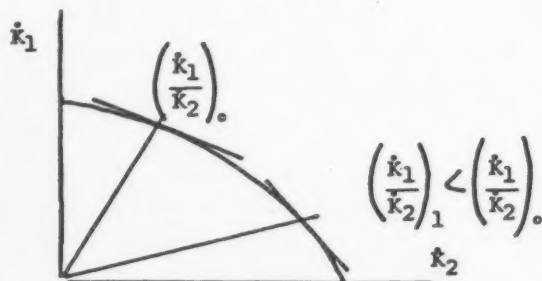
The problem requires (1) specification of functions $g(\cdot)$ and $h(\cdot)$, and (2) use of observable indicators for $\dot{K}_1$ and $\dot{K}_2$. Consider each in turn.

1. Specification of $g(\cdot)$ and $h(\cdot)$

(a) The main issue is that the function $g(\cdot)$ must be flexible enough to allow for a properly shaped production possibility curve (or isoproduct curve) in $\dot{K}_1$ and $\dot{K}_2$, (i.e., concave to the origin). This is equivalent to saying the marginal rate of transformation

$$MRT_{12} = \frac{\partial g / \partial \dot{K}_2}{\partial g / \partial \dot{K}_1}$$

is decreasing in $\dot{K}_1 / \dot{K}_2$ as below:



For example, it's easy to show that the Cobb Douglas form of $g(\cdot)$,

$$g(\dot{k}_1, \dot{k}_2) = A \dot{k}_1^a \dot{k}_2^b$$

generates by necessity the opposite shape. One wants to use a flexible form which, at least, allows (even if it does force) the right shape. To investigate just compute:

$$MRT = - \frac{d\dot{k}_1}{d\dot{k}_2}$$

and check that

$$\frac{d MRT}{d (\dot{k}_1 / \dot{k}_2)} < 0$$

One (but only one) possibility is CES:

$$(2) g(\dot{k}_1, \dot{k}_2) = [a\dot{k}_1^{-p} + (1-a)\dot{k}_2^{-p}]^{-\frac{1}{p}}$$

where the elasticity of substitution between $\dot{k}_1$ and $\dot{k}_2$ along isoproduct curve is $\sigma = 1/(1+p)$. One can check that:

$$- \frac{d\dot{k}_1}{d\dot{k}_2} = \frac{\partial g / \partial \dot{k}_2}{\partial g / \partial \dot{k}_1} = \frac{1-a}{a} \left(\frac{\dot{k}_1}{\dot{k}_2} \right)^{\frac{1}{1-p}}$$

Clearly, $-d\dot{k}_1/d\dot{k}_2$ rises as $\dot{k}_1/\dot{k}_2$ falls if $1-p < 0$ or $p > 1$. Other cases can be checked similarly.

(b) The specification of $h(R)$ is more open. A simple Cobb Douglas can be used. No concavity or convexity restrictions are required.

2. Use of Indicators for $\dot{K}_1$ and $\dot{K}_2$

We don't observe $\dot{K}_1$ and $\dot{K}_2$, but suppose we have some indicators such as patents P_1 and P_2 . For example, let

$$(3) \quad \begin{aligned} P_1 &= B_1 \dot{K}_1 + e_1 \\ P_2 &= B_2 \dot{K}_2 + e_2 \end{aligned}$$

where B's are propensities to patent and e's are measurement errors since P's are only indicators. Obviously P_1 is correlated with e_1 , but assume $\dot{K}_1$ and e_1 are uncorrelated and so are e_1 and e_2 . Then from (3)

$$(4) \quad \begin{aligned} \dot{K}_1 &= b_1 P_1 - b_1 e_1 \\ \dot{K}_2 &= b_2 P_2 - b_2 e_2 \end{aligned}$$

where $b_1 = B_1^{-1}$ and $b_2 = B_2^{-1}$.

Substituting (4) into the $g(\cdot)$ function in equation (2) yields the equation in terms of P's and e's. Since P's are correlated by (3), one must use an instrumental variable estimation technique on the P's which appear in $g(\cdot)$.